Review of Floods in India during the past 75 Years

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New Delhi

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—A PERSPECTIVE

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1. Introduction

The term flood has been defined by W. M. O. in different ways. The definition most appropriate for our present purpose is the following :

"*A Flood is a relatively high flow as measured by the stage height or discharge*".

We shall consider a flood as "severe" if the highest flood level recorded is at least 2 metres above the danger level at the gauging site. We would refer to a flood as "Catastrophic" if the damage caused by it is exceptionally heavy e. g. if it amounts at least to a few crores of rupees. This is not a satisfactory way of defining this term but nothing better could be done.

2 List of Severe and Catastrophic Floods

The author made a serious attempt to collect all the cases of severe floods during the period of 75 years included in his study i.e. during the period 1908 to 1982. The writer specially obtained the reports for the flood prior to 1923 from the Technical Head quarters of I. Met. Department at Pune. The available flood records in the Bombay University Library, the Central Library of the Maharashtra Government were also seen through. These records showed that destructive floods (apart from less severe ones), had occurred during the period 1908 to 1923. But important details such as the actual number of cases of floods, the duration of each of these floods, the times of occurrence of the floods etc. were not available. This was unfortunate but nothing could be done about them. The author could therefore discuss only the 79 cases of severe floods during the period 1923 to 1982 as given in table I

Table I

Basins or groups of rivers in which floods occurred	Number of occasions
(a) Indus-System and the Upper Ganga basin	15
(b) Lower Ganga basin	10
(c) Brahmaputra basin	9
(d) Central India rivers	28
(e) Peninsular rivers	17
Total	79

This Review article is based on the chapters prepared by the author for a detailed "Flood Monograph" which will be published by the India Meteorological Department.

Of the 79 occasions of severe floods, 20 could be classified as "Catastrophic". These are listed below :—

A List of the Catastrophic Floods : IS GI

1. Cauvery in July 1924.
2. Upper Ganga and Yamuna in October 1924.
3. Sabarmati, Mahi and the contiguous rivers in July 1927.
4. Khari (a tributary of Banas) in July 1943.
5. Rivers in Punjab (India) and severe floods in Jhelum in September 1950.
6. Kosi in July and August 1954.
7. Ravi, Beas, Sutlej, Yamuna and other rivers in Punjab (India) and Pepsu in October 1955.
8. Rivers in South Kerala in August 1958.
9. Tapi in September 1959.
10. Brahmaputra in August 1962.
11. Brahmaputra and the rivers in South Assam (including Nagaland, Manipur and Tripura) in June 1966.
12. Tiesta (tributary of the Brahmaputra) in October 1968.
13. Narmada in September 1970.
14. Rivers and streams in Tamil Nadu in December 1972.
15. Sone and the Ganga in and around the city of Patna in August 1975.
16. In the districts of Madurai, Pudukkottai and Tiruchirapalli in Tamil Nadu November 1977.
17. In Gangetic West Bangal in the last week of September 1978.
18. Near Morvi in Saurashtra in August 1979.
19. Rivers in Uttar Pradesh in July 1980.
20. Rivers in Assam in July 1981.

Table II below shows the areas and mean slopes of some of the major rivers in India as given in the Unesco World Catalogue of Very Large Floods (1976).

Table II

Rivers	Areas (Sq Km)	Mean slopes of River
1. Ganga (Farakka)*	935,000	0.226
2, Brahmaputra (Pandu)	404 000	0.250
3. Godavari (Dowlaishwarm)	309,000	0 046
4. Krishna (Vijayawade)	257,000	0 063
5 Mahanadi (Baramul)	127,000	0 062
6 Tapi (Kathore)	64,400	0.092
7. Kosi (Sunakhambikola)	66,900	1 030
8 Narmada (Garudeshwar)	87,800	0.054

*Names given in brackets are of the gauging sites.

Table III shows the maximum duration of flood and the maximum time to reach the peak in representative cases for some of the major rivers in India (Unesco catalogue of Very Large Floods 1976).

Table III

Rivers	Maximum duration of the flood (Hours)	Maximum time to reach peak (Hours)
1. Ganga	1956 (Aug. 1958)	720 (Aug. 1961)
2 Brahmaputra	1320 (July 1955)	840 (Aug. 1957)
3. Mahanadi	792 (Aug. 1964)	528 (Aug. 1964)
4 Krishna	720 (Sept. 1898)	384 (July 1948)
5. Narmada	696 (Sept. 1959) and Aug. 1964)	504 (Sept. 1949)
6 Godavari	528 (Sept 1943)	240 (Aug. 1946)
7. Kosi	462 (July 1948) and Aug. 1950)	264 (July 1948)
8. Tapi	432 (Aug. 1946)	168 (Aug. 1944)

CASE No. 1

CATASTROPHIC FLOODS IN THE CAUVERY AND SEVERE FLOODS IN THE RIVERS IN KERALA AND COASTAL KARNATAKA IN JULY 1924

1. Introduction

This is a case of extraordinary interest as it constituted record floods in the Cauvery. Banerji and Narayanan (1966) had made an elaborate hydrometeorological analysis of this case and also of all flood situations in the Cauvery between 1892 and 1956 and in 1961. Their analysis, included the study of normal isohyets over the catchment in June, July, August and September and of the actual isohyets in the 54 spells of 6 days' duration each. They found that the normal isohyets in June, July, August and September and the isohyets in the 54 spells were confined to a narrow belt of 5000 sq. miles (12950 Sq. kms) of the Western Ghats. This area in the *upper catchment* therefore, according to the authors, *forms the real watershed for floods in the plains of the Madras State* (*Tamil Nadu*).

The authors have also stated that the discharge of the Cauvery near Tiruchirapalli was 13000 cumecs in the July 1924 floods and 11200 cumecs in the 1961 floods.

The authors have made a brief reference to the synoptic situations during the 54 spells. The number of types of synoptic situations associated with the floods, according to them, were :

(i) active monsoon — 13

(ii) strengthening of the monsoon due to Bay of Bengal depressions — 38

(iii) strengthening of monsoon due to Arabian sea depressions — 3.

The authors have however not produced any synoptic evidence in support of their statement.

Parthasarathy and Sarker (1966) have made a detailed hydrometeorological study of the severe floods in the Cauvery during the period 26 June to 7 July 1961. They have also briefly referred to the large-scale synoptic situation associated with these floods. In their opinion, the 1961 flood was comparable to the July 1924 flood but was somewhat less in severity. They have stated that the total amount of precipitation in the 1924 floods was about 14300 megatons compared to 12400 in 1961.

In the opinion of the present writer also, both the July 1924 and July 1961 floods could be considered as comparable. The writer has therefore summarised below, his detailed findings in the July 1924 case only. He has laid far more emphasis on the synoptic aspect than on any other aspect.

2. Basin plan of the Cauvery

The Cauvery rises at Bhagamandala (12°25'N, 75°34'E) in the Brahmagiri range of the Western Ghats in the Coorg District in Karnataka at an elevation of 1340 metres. After flowing about 800 kms, the river joins the Bay of Bengal at Kaveri-

patnam in Tamil Nadu as a small stream, all its water having been utilised higher up (Rao, K. L. 1975).

3. Large-scale synoptic situation

The writer has carefully investigated into the possible basic synoptic causes which could have led to the very heavy rainfall and the consequent catastrophic floods in July 1924. Unfortunately, complete absence of upper air data had made the problem very difficult. The floods could not be attributed to any depression or any other cyclonic disturbance in the Arabian Sea or the Bay of Bengal. In fact, no well-developed depression formed in either of the Indian seas during July 1924. The pressure gradient at sea level along the west coast did not also give any clue to the large-scale mechanism responsible for the floods.

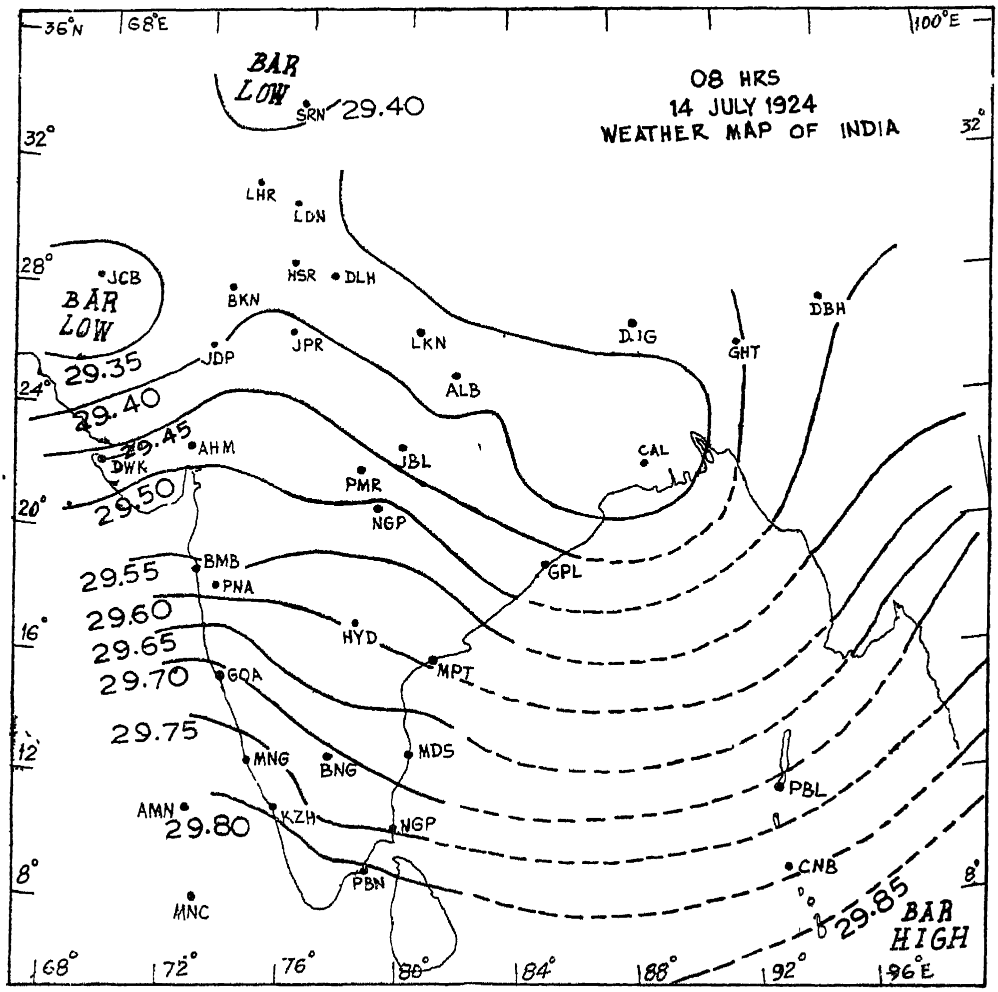


Figure 1.1

Figure 1.1 shows the sea-level isobars at 08 hrs on 14th July, 1924 i e. 24 hours prior to the occurrence of rainfall reported on the morning of 15 July vide Table 1.2. Figure 1.2 shows the isobars at 08 hrs of 15th i.e. after the rainfall referred

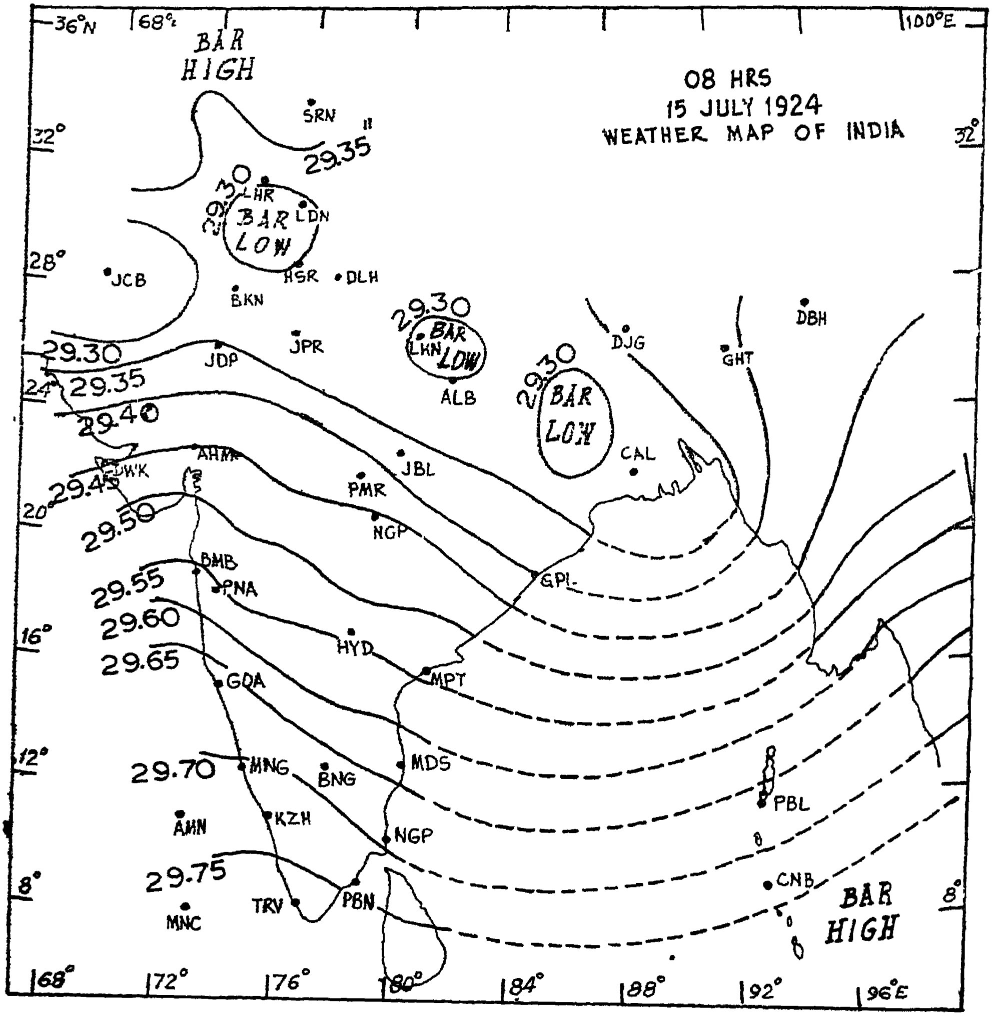
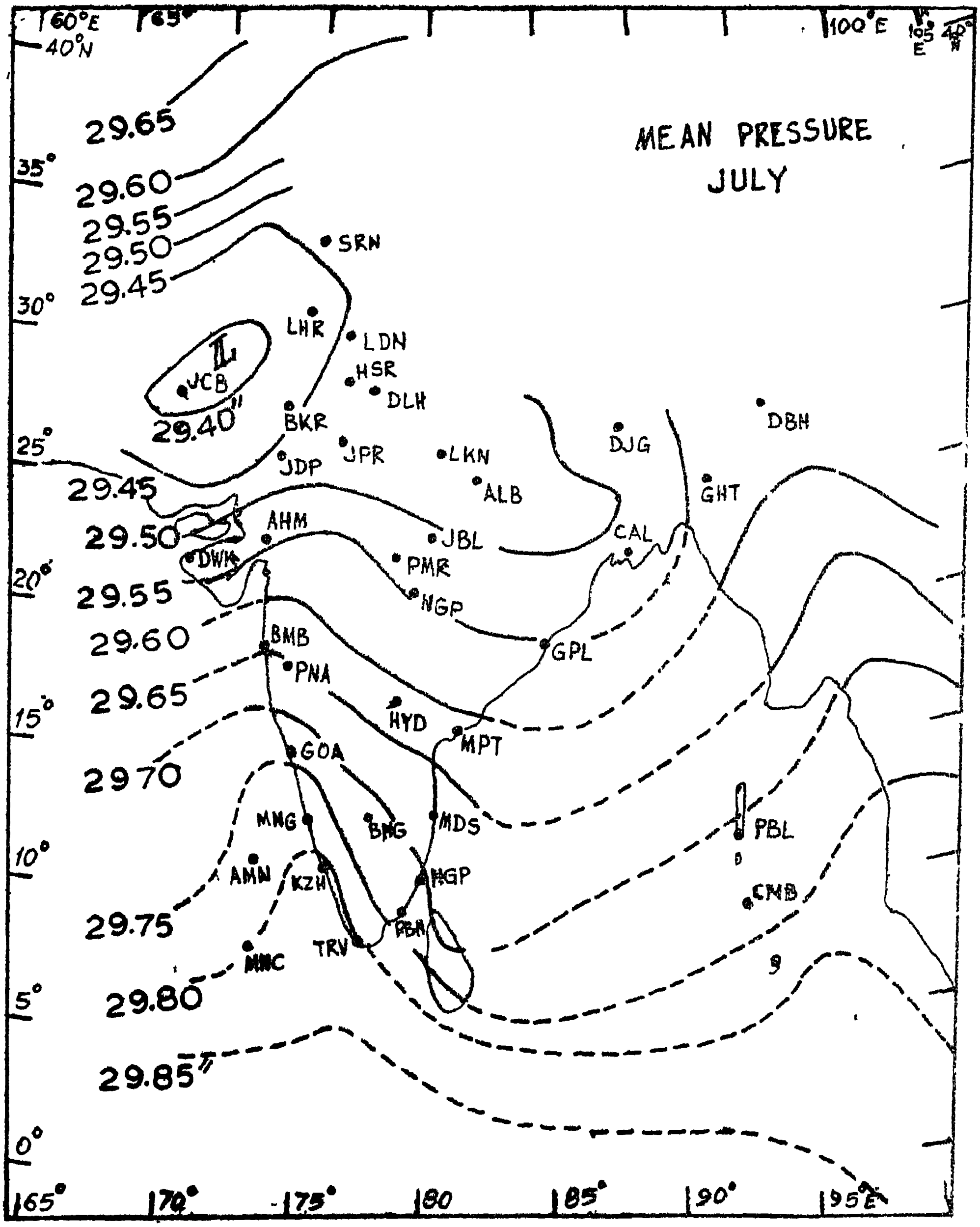


Figure 1.2

to above had occurred. A comparison of the sea-level isobars before and after the rainfall had occurred (Compare Figures 1.1 and 1.2) and a comparison of both of them with the normal isobars (Figure 1.3) do not reveal that there was any striking increase in the steepness of the sea-level pressure gradient between 10°N and 13°30′N either on the 14th or 15th compared to the gradient in the normal chart (Figure 1.3). The position was also not significantly different on any of the other days for which rainfall figures have been given in Table 1.2.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80
85°
90°
95°E

Figure 1.3

Table 1.1 *Average surface wind speeds (m.p.h.) in the past 24 hours ending at 8 A. M, during the period 10 to 26 Jnly 1924*

Stations	10	11	12	dates 13	15	15	16	17	18
Mamagao	6	9	13	10	8	10	11	12	13
Karwar	2	5	8	8	8	—	—	—	—
Mangalore	6	9	9	8	8	11	11	—	—
Mercara	6	10	10	10	7	10	11	12	11
Kozhikode*	1	5	4	5	9	6	14	—	—
Cochin	1	2	5	3	5	9	14	—	—
Trivandrum	4	4	5	6	7	7	7	6	5

Table 1.1 (*Contd*)

Stations	19	20	21	dates 22	23	24	25	26
Mamagao	14	—	10	10	13	11	14	10
Karwar	5	5	4	8	6	15	—	6
Mangalore	—	—	—	8	7	—	—	—
Mercara	11	9	11	9	6	6	—	—
Kozhikode*	—	—	—	—	—	—	—	—
Cochin	—	—	—	—	—	—	—	—
Trivandrum	6	9	7	6	8	5	7	—

*Kozhikode is the same as Calicut which was the name in vogue in the British Period.
N. B. :—represents missing reports.

4. Average surface wind-speed in 24 hours

Table 1.1 shows the average surface wind-speed in the past 24 hours ending at 8 A.M. on each of the days during the period 10 to 26 July 1924. The average wind speeds have been measured with calibrated anemometers. The figures have been extracted from the *Indian Daily Weather Reports* published by the India Meteorological Department. From the point of view of our present study of the rainfall over the Cauvery Basin, observations of Mangalore, Mercara and Kozhikode are the most important ones. The purpose in investigating into the wind-speeds is to assess how far forced ascent of the moist air over the Western Ghats is responsible for the observed differences in rainfall.

Table 1.2 *Rainfall of 5" (127 mm) or more in 24 hours in Coorg District 11-24 July 1924*

Stations in Coorg/Dates Dist.	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Mercara					136	152	364				127		184		140
Virajpet					127	221	269				137	146	175	172	332
Somwarpet						238	160					133		160	
Ammatti					152	284	251	132	133			128	192	292	411
Napoklu			163		173	160	323	127	163		154	146	187	234	262
Sanivarsante					264										
Ponnampet			161	209	227	161	157							173	303
Bhagamandala	144	160	213	237	368	431	494	239			336	282	435	540	842
Sunticoppa					170	222									

Table 1.3 *Rainfall of 5" (127 mm) or more in 24 hours—12-25 July 1924*

Stations in Malabar Date Dist	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Alattur						161								
Palghat						197								
Parli				127										
Ottappalam						174						153		
Cherpulchery					222	174						173		
Mannarghat					182	218		138			251	149	170	
Perintalmanna					153	196					131	211		
Manjeri					132	234		136			159	273		
Nilambur					229	321					282	238		
Vayittiri	178			203	290	331	156	137	128	147	277	279	204	239
Manantoddy		158	128	137	233	300				145	276	280	306	214
Irikkur	133					218	185			160		141	188	
Payyannur						151	152			129				
Taliparamba						169	166		137	144				
Cannanore						263	201			174				
Tellicherry						178	184							
Badagara						159	178					129	128	
Kuttiyadi					151	221	169	131			163	144	172	
Quilandi									134	128				
Calicut									174			169		
Tirurangadi									137			187		
Ponnani												187		
Chowghat												221		
Triprayar							128					153	161	

N. B. The so-called Malabar district in 1924 included many stations in the present coastal Karnataka.

It will be observed that there is a slight increase in the average speeds on the 15th compared to 14th at Mangalore and Mercara but *not at Kozhikode*. The dates of heavy rainfall over stations in the Coorg District between 11th and 25th in Table 1.2 may also be compared with the rise and fall of the average surface wind-speeds in Table 1.1. There are not any large and consistent differences in the average surface wind-speeds to enable us to make any categorical statement. The writer is aware that the method adopted by him to estimate the forced ascent of monsoon air is not the best one to establish that the higher the wind-speed, the larger would be the rainfall due to orographic effect. However, as upper wind data were not available, this was the best that could be done by him with the available data. No undue importance should therefore be attached to the figures given in Table 1.1 or the conclusions derived therefrom.

5. The study of the 1961 Floods by Parthasarathy and Sarker

Incidentally, it may be mentioned that Parthasarathy and Sarker (1966) have given a few details regarding the winds in the lower and upper troposphere in association with the 1961 floods. They have also suggested that the floods in June-July 1961 were associated with active monsoon conditions along the west coast and that these conditions were probably connected with certain synoptic developments in the Bay of Bengal. The present writer has made a general study of the available data in the 1961 case. In his opinion, the synoptic situation has to be studied in much greater depth before we can state with confidence about the situation which caused the floods in 1961.

6. The writer's General Conclusions about the July 1924 Floods

In view of what has been stated above, the writer has come to the conclusion that the explanation for the large-scale heavy rainfall has to be sought for either in the meso-scale factors in the lower layers of the atmosphere in the hilly area (about which we have no information) or in perturbations higher up in the troposphere in the form of waves in the easterlies or in the movement of high-level easterly jet maxima (Koteswaram 1958, Ramaswamy 1972, Rao Y P 1976).

7. Severe Floods in Kerala in July 1924

The author has not been able to obtain detailed information in respect of the severe floods in Kerala. He would therefore merely state that, as in the case of the Cauvery floods, the pressure-gradient at the surface did not give any clue to the heavy rainfall and that the large-scale mechanism responsible for the heavy rainfall may be sought for :

(a) in off-shore vortices along the west coast (George P A 1956, Mukherji et al 1978) which the auther could not study for want of data and

(b) in the upper air as enumerated under the discussions on the Cauvery floods

Table 1.3 contains a statement of rainfall of 5″ (127 mm) or more in 24 hours over the *coastal area known as the Malabar district during the period 12 to 25 July 1924.

8. Flood Damage

The heavy rain which fell in coastal Karnataka, over the Coorg District and the neighbouring areas on the Ghats, is reported to have caused severe floods in the rivers in those areas. In the Udipi taluka in coastal Karnataka, several villages were washed away and about 10,000 people rendered homeless. Details of the flood-damage in other areas are not available.

*In pre-Independent India, the area know as "Malabar district" was under the direct control of the British Government in India.

CASE No. 2

CATASTROPHIC FLOODS IN THE UPPER GANGA AND THE YAMUNA IN OCTOBER 1924

1. Source of the Important Antecedent Precipitation

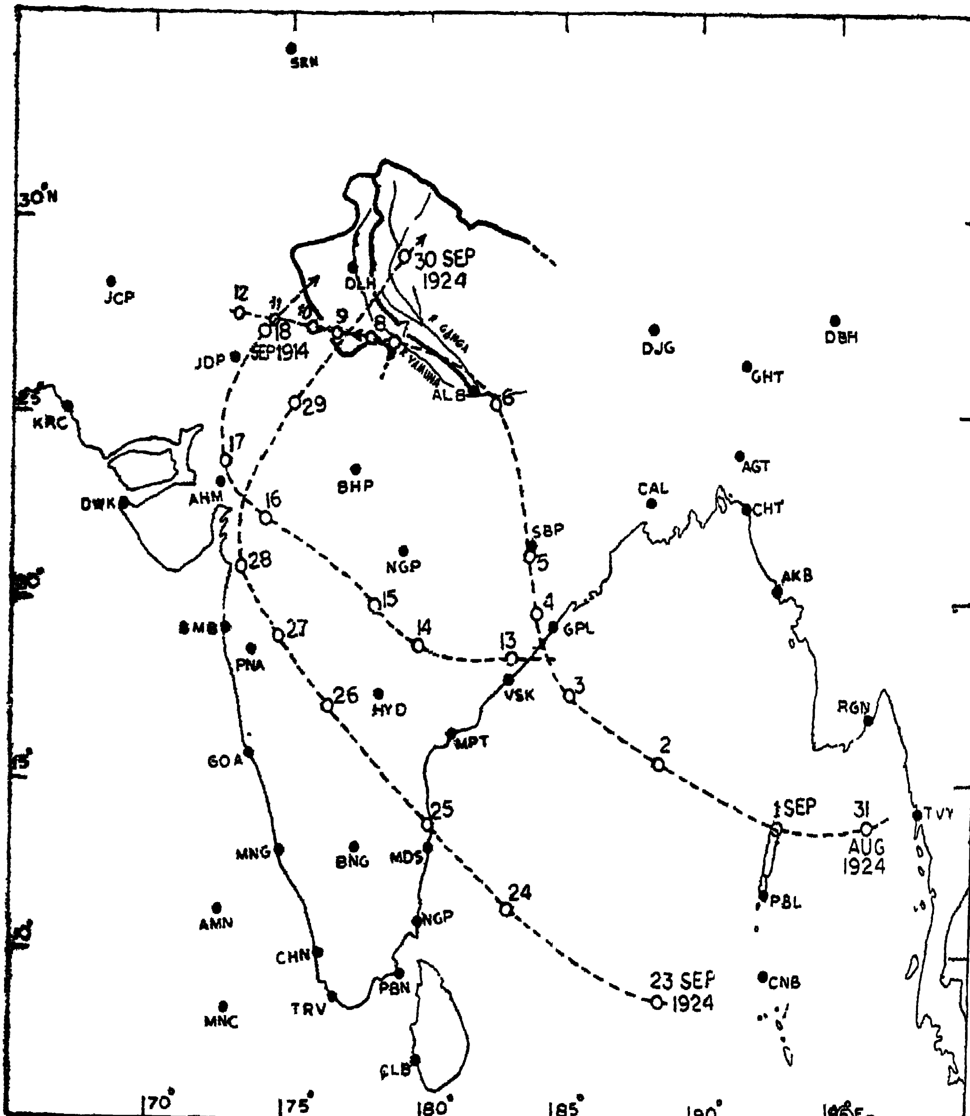
Although the basic cause of the floods is to be attributed to a long-travelling depression with an unusual type of recurving track, there is evidence to suggest that the base-flow in the Ganga and the Yamuna prior to the development of the catastrophic floods must have been higher than usual in the first three weeks of September 1924. These important antecedent conditions occurred in association with a depression which formed over the Andaman Sea on 31st August 1924, was centred near Varanasi on the morning of 6 September and lay to the south-east of Agra on the 7th. Although the departure of pressure at the centre of the depression at this time was almost negligible, this is not an unusual characteristic of September depressions—it retained its identity as a depression and was influencing winds at least upto the levels of low clouds. In the next two days, it moved very slightly to the west of Agra but travelled somewhat more rapidly thereafter towards east Rajasthan.

2. Main Synoptic Situation

The subsequent heavy rainfall in the catchment of the Ganga and the Yamuna occurred in association with the depression of 23-30 Sept. 1924, (Fig. 2.1). It formed near Lat 8½°N Long. 88½° E in the Andaman Sea on the morning of 23 September and passed through Maharashtra on 27th. The track of the depression then became NNW/N. It subsequently curved to northeast and disappeared over the Simla-Kumaon hills on 30th September after causing exceptionally heavy and continuous rain there as well as over the adjacent plains from the 27th to 29th.

2.1. Is the Heavy Continuous Rain over the Simla-Kumaon Hills due to Orography ?

According to the Annual Summary for 1924 published by the India Meteorological Department, exceptionally heavy and continuous rain occurred in the Simla-Kumaon Hills because the line of advance of the depression "was practically perpendicular to the line of the Himalayas and the humid southerly current in the eastern semi-circleof the depression fed both from the Bay and the Arabian Sea, was being continuously forced up against the same part of the Himalayas namely the Simla-Kumaon hills". The present writer however holds a different view. His view is based on a study of similar cases of recurving depressions, based on upper air data received at the Northern Hemisphere Exchange Centre after the latter was opened at Delhi in 1963. These data have enabled the writer to study such cases of recurvature in great detail. He has established that the recurvature takes place in association with the intrusion of troughs in the middle-latitudes westerlies equatorwards and the consequent alteration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GPL
VSK
MPT
RGN
TVY
PBL
CNB
30°N
70°
75°
80°
85°
90°
95°E

Figmre 2.1

in the position and configuration of the sub-tropical high to the east of the trough in the upper troposphere (Ramaswamy, 1965, 1968 etc). He has also established elsewhere (Ramaswamy 1972, Ramaswamy and Kailasanathan 1976) that orographic contribution, though important, is certainly less important than it has hitherto been considered to be.

2.2 Indirect Met eorological Evidence in Support of the Author's view

It is relevant to note that the movement of a rain-belt from west to east across N.W.F.P. (Pakistan) and Kashmir gives fairly clear evidence that the recurving of the September 1924 depression to northeast after 27 September was also caused by the same mechanism as the one postulated by the author in the recent cases studied by him.

3. Rainfall Analysis

In the India Weather Review for 1924, the India Meteorological Deptt., has presented an excellent analysis of the rainfall associated with this disturbance. The analysis clearly shows how elegantly the available rainfall data could be re-hashed and presented so as to bring out the essential features of the development connected with the disturbance. We are reproducing below 4 sets of these rainfall tables which speak for themselves.

Table 2.1 *Rainfall (mm) averaged over the districts for the 3 days ending at 0800 hrs, on 30th September 1924*

	September 1924		
	27th	28th	29th
West Uttar Pradesh :			
Districts :			
Dehra Dun	137	185	102
Garhwal	163	178	51
Almora	137	196	2
Nainital	147	104	2
Shaharanpur	99	135	160
Bynor	155	185	104
Bareilley	63	165	Nil
Philibet	74	135	Nil
Muzaffarnagar	79	112	129
Meerut	71	125	109
Bulandshahar	112	63	38
Moradabad	201	94	8

Table 2 1 (*Contd.*)

Buduan	114	64	Nil
Aligarh	109	41	2
Mathura	99	30	Nil
Punjab, Haryana & Himachal Pradesh			
Districts			
Simla	119	142	61
Ambala	74	99	160
Karnal	36	56	109
Rohtak	25	46	76
Gurgaon	30	61	66

Table 2.2 shows the stations which recorded heavy rainfall of 10″ (254 mm) and over in 24 hours during the period 27 to 29 September.

Table 2.2

27th	Lansdowne	270 mm, and Kılba 254 mm.
28th	Lansdowne	323 mm, Hardwar 305 mm, Mussoorie 260 mm, Faridpur 275 mm, and Bıronkhal 255 mm.
29th	Lansdowne	254 mm, Naiashahr 254 mm and Kalsıa 267 mm.

The author's opinion is that, even in the September 1914 case, there was evidence of the movement of a rainbelt from west to east across the N.W.F.P. (Pakistan) and Kashmir before the monsoon depression began recurving towards the northeast.

Thus, a middle latitude trough in the westerlies must have intruded into lower latitudes and been indirectly responsible for the recurvature of the monsoon depression. The author does not however deny that orographic effect must also have been an additional factor in the occurrence of very heavy rainfall in the September 1914 as well as September 1924 cases.

4. Flood Damage

The abnormally heavy and continuous raın in association with the September 1924 depression, caused catastrophic floods in October 24 in the Ganga and the Yamuna, which resulted in widespread and very serious damage in Uttar Pradesh and Punjab (India) and Haryana. According to the official reports, areas covering roughly about 5500 sq. miles were affected, where about 242,400 houses were washed away and 1100 persons and about a lakh head of cattle, were drowned. Besides, considerable damage was done to canals and bridges in Saharanpur and Dehra Dun districts, to channels and tributaries in Garhwal and to railways and other communications in several divisions. The damage to communications in the Kumaon division was estimated at 15 lakhs of rupees. At Nainital, the landslide of the Chakrata Hill caused a damage of

about 1 lakh of rupees to the Government buildings. In Punjab (India) and Haryana the damage was moderate in Gurgaon and Rohtak districts and very severe in the Karnal and Ambala districts. In Karnal, 14,800 houses were demolished, 92 persons lost their lives and 30,000 animals were swept away; in Ambala, 68 villages were affected and the number reported drowned exceeded 50, whilst the loss in cattle was estimated at several thousands.

CASE No. 3

CATASTROPHIC FLOODS IN THE SABARMATI, MAHI AND CONTIGUOUS RIVERS IN JULY 1927

1. Introduction

This is one of the most important cases of floods studied by us. Unfortunately, however, the floods occurred during a period when upper air data even over India were extremely scanty. We are therefore unable to state in precise terms, the basic meteorological factors which led to these floods. We shall at best be able to make a few comments which may sound rather speculative but which are based on our analysis of similar situations in recent years.

2. Large Scale Synoptic Situation

The track of the monsoon depression associated with these floods in Gujarat may be seen in Figure 3.1. The portion of the track of the depression relevant to the flood-

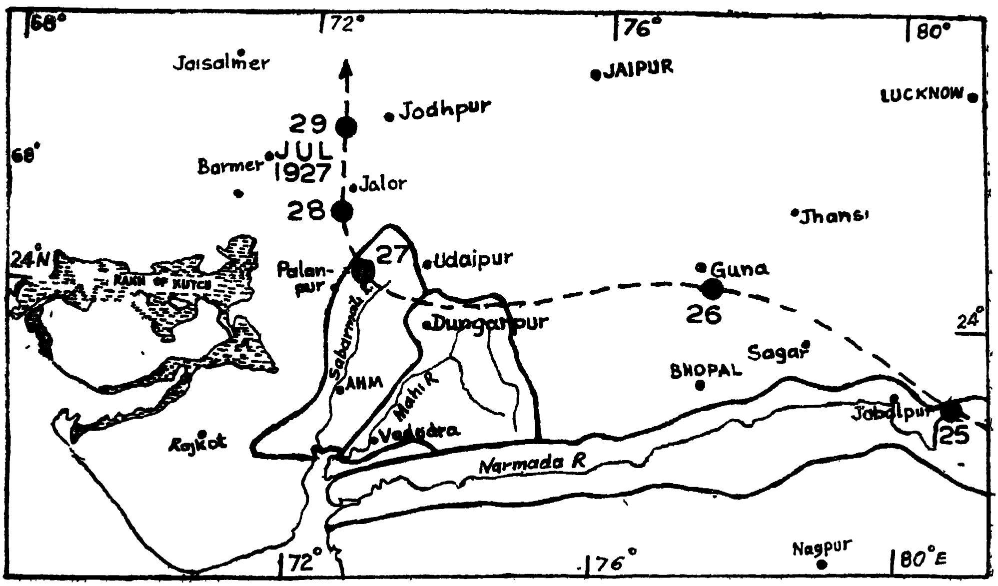


Figure 3 1 Floods in Sabarmati, Mahi & Contiguous Rivers

situation has been shown in the diagram. The depression formed in the northwest angle of the Bay on 23rd July as a depression of small extent but with a pressure deficiency of nearly 9 mb. At 08 hours of 26th when it was centred near Guna, the pressure deficiency at its centre was about 10 mb. By 08 hours of 27th when it was not far from Palanpur, the deficiency was about 14 mb. It will thus be noted that the depression went on intesifying until it reached Palanpur Then started the intriguing phase of the movement of this depression It slowed down considerably in its movement and at the same time curved to the north The centre lay somewhat to the west of Jodhpur on the 29th. By this date, the depression had also somewhat weakened; the pressure departure from normal became 9 mb. The depression then moved fairly rapidly and weakened considerably by the morning of 30th. It disappeared over the Punjab hills on the next day.

3. Mechanism of the Phenomenally Heavy Rainfall

Figure 3.2 shows the sea-level map at 08 hours on 27th July 1927 and the rainfall in inches which had occurred in 24 hours ending at 08 hours on that day. The map has been reproduced from the fuller map published in the Indian Daily Weather Report of the Governmet of India Meteorological Department. The most interesting portion of Figure 3 2 is the region enclosed by the stations Ahmedabad (23°02'N, 72°85'E), Deesa (24°14'N, 72°12'E) and Udaipur (24°35'N, 73°42'E). This area is one of very marked convergence (at sea-level) between the fresh monsoon southwesterlies and westerlies, the deflected monsoon easterlies and northeasterlies and the moist northerlies and northwesterlies. This area has been popularly referred to by some meteorologists as the "Triple point". Note from Figure 3.2 that Ahmedabad had 16 rain (406 mm) in the subsequent 24 hours. The convergence would have been more clearly seen in the 850 and 800 mb. levels but unfortunately no upper air charts were available for any of the days connected with this remarkable depression.

By 27th morning, the configuration of the sea-level isobars had significantly changed. The isobars which were elongated in an E-W direction on 26th had become more oblong and were more oriented in a north to south direction. Such a change in configuration is usually considered as one of the features associated with curving of a depression to the north.

The depression very slowly curved to the north and *all the time the region of convergence lay over the catchment of the Sabarmati* (Figure 3.1). The slowness of curving to the north is obviously connected with the weak winds over the same region at the "steering level" in the upper troposphere.*

On the basis of our synoptic experience in similar cases, in which upper air data were available, we are led to postulate that phenomenally heavy rainfall occurred over and near the Sabarmati catchment for the following reasons :

*The author is aware that the precise mechanism responsible for the steering of cyclonic systems is still a controversial issue However, as pointed out by him elsewhere (Ramaswamy 1972) we shall accept the currently—prevalent idea namly that the configuration of the flow—patterns above a level which is not influenced by the lower level cyclonic system, controls the direction and speed of movement of the cyclonic system.

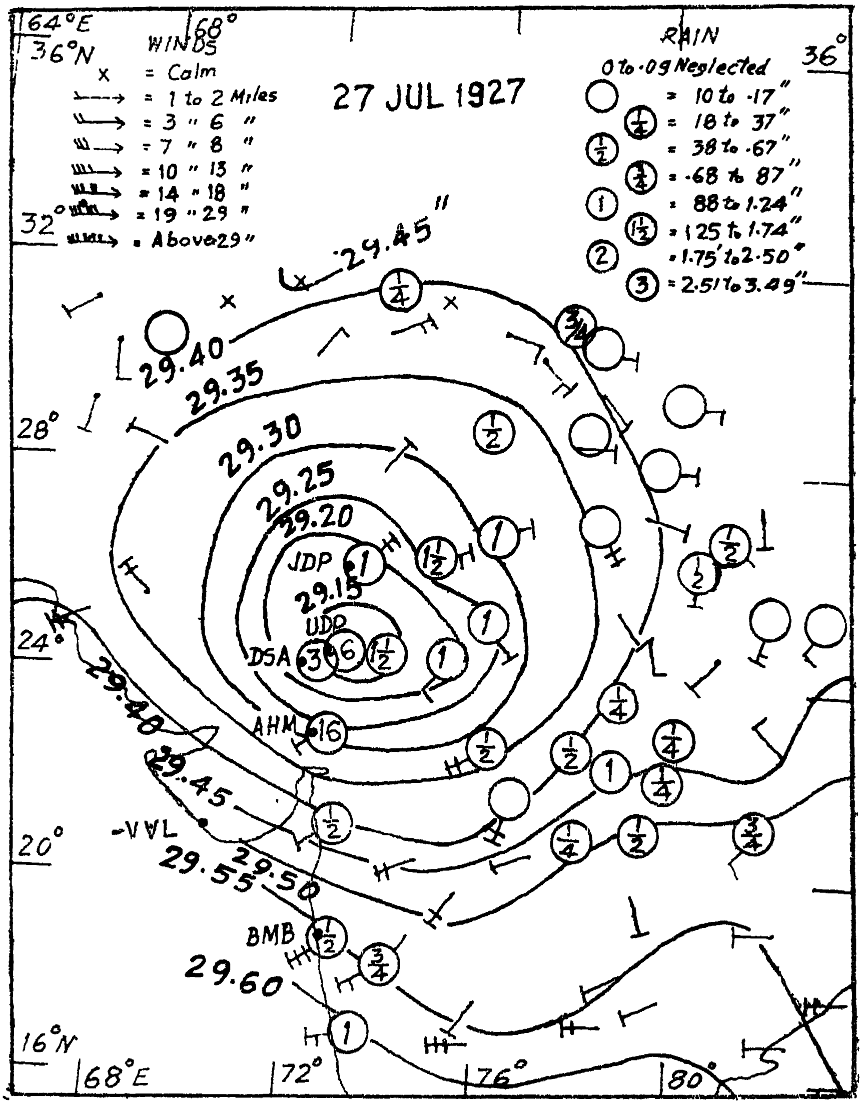


Figure 3 2

(a) the "Triple Point" region lay over the Sabarmati catchment for an unusually long period on account of the location of an E-W oriented upper tropospheric high and the weakness of the winds at the western extremity of the high;

(b) the Arabian Sea was sufficiently near the field of the depression to provide continuous supply of fresh monsoon air into the field of the cyclonic circulation.

4. Rainfall Analysis

The depression caused continuous and phenomenally heavy rain in Gujarat and the Mount Abu region during the period 24th to 29th, Table 3 1 below shows district averages of rainfall over Gujrat (including Kathiawar)

Table 3.1 *District Averages of Rainfall in July 1927 (mm)*

Districts/Dates	24	25	26	27	28	29
Broach	15	51	79	107	99	8
Kaira	79	191	208	279	257	43
Panchmahal	35	84	302	183	216	48
Ahmedabad	84	124	86	160	203	81
Rewa Kantha	23	35	180	135	140	38
Palanpur	74	35	99	79	155	101
Mahi Kantha	28	38	116	129		94
Kathiawar	33	81	33	127	81	15

Falls of 254 millimetres and more in 24 hours occurred at most stations. Table 3.2 shows the most noteworthy falls in this deluge.

Table 3.2 *Rainfall of 254 mm. or more in 24 hours in July 1927 at individual stations (mm).*

Stations/Dates	24	25	26	27	28	29	30
Kaira District:							
Dakor		264	292	457	541	41	
Panch Mahal:							
Kalol		145	361	249	391	76	
Ahmedabad:							
Ahmedabad	124	152	135	414	287	129	
Dholka		254	190	183	216	41	
Sanand	129	241	76	241	246	76	
Rewa Kantha:							
Wadasinor		7	246	254	333	58	
Mahi Kantha:							
Mohanpur		152	170	262	168	68	
Dhrangdhora		442	63	190	114	46	213
Mount Abu		246	109	160	129	277	

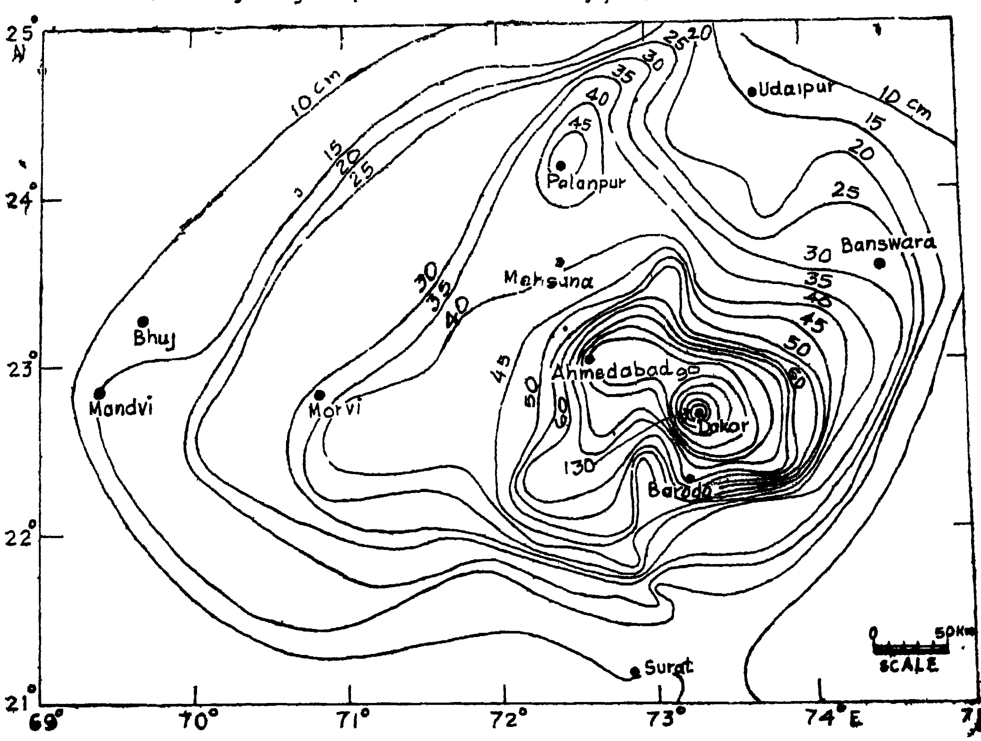
According to the monthly weather report of I. Met D, 1270 mm. of rain were recorded at Ahmedabad during the course of six days of which 737 mm. fell within 48 hours. Other stations near Ahmedabad had also recorded heavy falls. Viramgam reported 6940 mm. in 7 days.

5. Isohyetal Analysis

Dhar, Rakecha and Mandal (1980) have recently made isohyetal analyses and worked out areal rain-depths of a large number of rainstorms associated with tropical disturbances such as depressions, cyclonic storms and severe storms in India. They have found that the September 1880 and July 1927 rainstorms over plain areas in this country gave highest areal rain-depths. These rain-depths have been worked out by the authors for different areas and durations. They have also compared them with similar aereal rain-depths over the tropical regions of U.S.A.

Figures 3.3 and 3.4 show three-day isohyetal pattern of 26-28 July 1927 and six-day isohyetal pattern of 24-29 July 1927 i.e. in the case of rainstorms associated with the catastrophic floods in Gujrat studied by us. It will be noted from these diagrams that the centre of the heaviest rainstorm in the 1927 case, lay at the station called Dakor (22°45'N and 73°09'E) which is about 70 km to the southeast of

Three day isohyetal pattern of 26-28th July, 1927 rainstorm



(Courtesy EDITOR, ARCH MET GEOPH BIOKL)

Figure 3.3

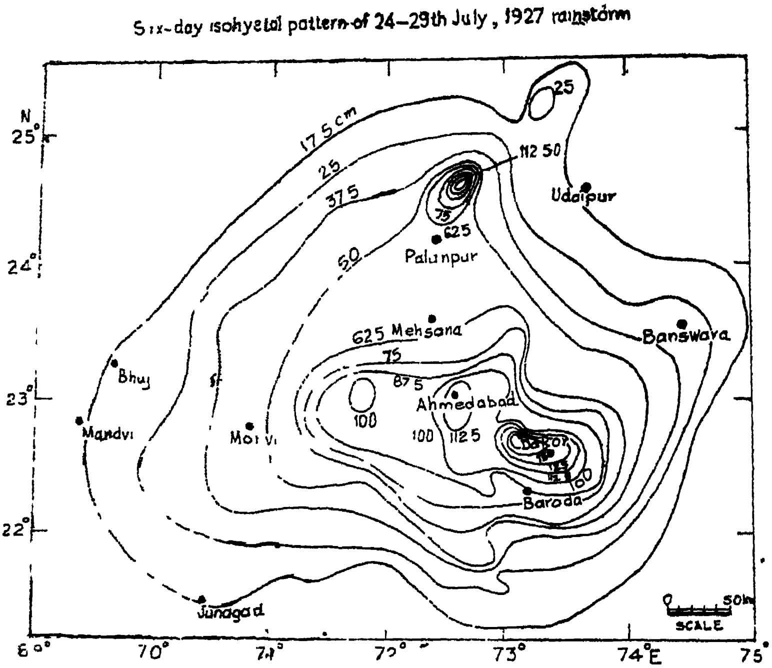


Figure 3.4 Six-day isohyetal pattern of 24-29th July, 1927 rainstorm

Ahmedabad. Dakor recorded about 166 cms of rainfall during the 6-day period of the rain-spell of which about 100 cms fell on two days i.e. on 27 and 28 July. It may be incidentally noted that the isohyets are based on the data of a large number of raingauge stations although only a few of them have been shown by us in Figures 3.3 and 3.4.

According to Dhar et al, the July 1927 rainstorm of 6-day duration gave the highest areal-depths for areas of 77700 sq. km and above for 1-day duration and for 64750 sq. km and above for 2-day duration. For all other durations from 3 to 6 days, the rainstorm gave the highest rain-depths which have not been exceeded so far in the plain areas in India.

Areal depths of rainstorms in U.S.A. were available to the authors upto a period of 3 days only. Similar figures for other countries in the world were not available. Without going into further details about these, we can state that the aerial depths of 3 days duration and more *contributed by the July 1927* (and September 1980) rainstorms are the world's greatest aerial rain-depths for duration of 2 days and above. This is an important conclusion and has therefore been included in this monograph.

6. Flood Damage

The following is an account of the havoc caused by the floods as published in the India Weather Review (1927) by the Government of India Meteorological Department.

"The exceptionally heavy and persistent rainfall gave rise to disastrously severe floods in Gujarat causing extensive damage to property and loss of many lives. Villages in many Talukas were destroyed and houses collapsed. Telegraph posts were uprooted and railway lines washed away. The Punjab mail became marooned at Itola and the passengers had to be transhipped across a sheet of water 300 feet wide. Some places were completely cut off and telegraphic and railway communications with them became impossible for a few days until repairs could be effected.

The Kaira and Ahmedabad districts and a portion of the Broach district (Baroda) and numerous villages in Kathiawar were submerged under water. Many villages were deserted by terrorstricken inhabitants. Ahmedabad, Dhola, Sanand, Viramgam and Dhanduka were completely cut off. Baroda was isolated with water 10 feet deep all round and remained in this state for five days; the water is reported to have rushed through some streets in torrents, while in several streets in Dandia Bazar it was as much as 20 feet high. Six villages along the southern bank of the Dhodar were surrounded with flood water. The river Narbada was in high flood while water rose about 20 feet in the Sabarmati.

In Ahmedabad, according to official figures, the number of houses collapsed was 5098 and the damage was estimated at over 22 lakhs of rupees. Owing to house collapses, 6 men died, 10 were injured and about 40,000 (mostly mill workers with their families and children) rendered homeless. In the villages, crops suffered serious damage, entailing a loss of about three lakhs of rupees. Serious damage was also done to cotton crop in the Broach district. In Baroda a large number of houses fell resulting in the death of more than 50 persons and many animals, including rare ones in the zoo, were drowned and carried away by water.

The total damage by the flood amounted to about 2 crores of rupees, in round figures, of which half was suffered by Ahmedabad".

CASE No. 4

CATASTROPHIC FLOODS IN THE KHARI (A TRIBUTARY OF THE BANAS) IN JULY 1943

1. Hydrological Data

These floods would probably come under the category of "Flash Floods" as the catchment of the river in which they occurred was a small one (Figure 4.2). No hydrological data were however available for the river.

2. Large Scale Synoptic Situation

A cyclonic storm developed over the Bay of Bengal on 9th July. After it weakened into a depression, it moved across the central parts of the country and filled

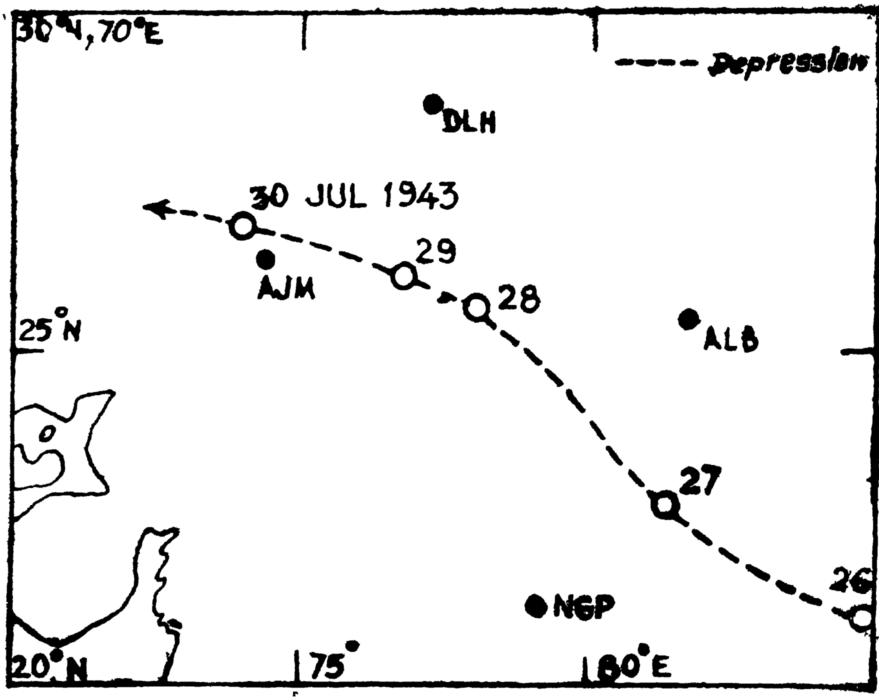


Figure 4.1 Track of Bay of Bengal Cepession 26-30 July 1943

up over Rajasthan on 15th July. A land depression developed over Central Bengal (in Undivided India prior to Independence) on 17th July and filled up over northeast Rajasthan on 21st. Subsequent to this, a cyclonic storm developed over the Bay of Bengal on 25th July. It weakened into a depression after crossing the Orissa coast and moved northwestwards. It passed to the *north of Ajmer* in northeast Rajasthan and lay on the morning of 30th about 80 kilometers to the northwest of Ajmer. It merged into the seasonal low over Sind (now in Pakistan) by the morning of 31st July. It will be seen from the above that *three cyclonic systems moved into east Rajasthan one after the other in quick succession in the second half of July 1943*. It was however the last of these three systems which was directly responsible for the catastrophic floods in the river Khari in the southeastern corner of the Ajmer-Merwara region. The previous two cyclonic systems had apparently provided very favourable antecedent rainfall over these areas. The track of the third depression is shown in Figure 4.1. The catchment of the Khari may be seen in Figure 4.2.

3. Rainfall Analysis

Table 4.1 shows rainfall over the Ajmer-Merwara region of 75 mm or over in 24 hours between 15 and 30 July. It may be of incidental interest to add that the average rainfall over the Ajmer-Merwara region taken as a whole between 29 and

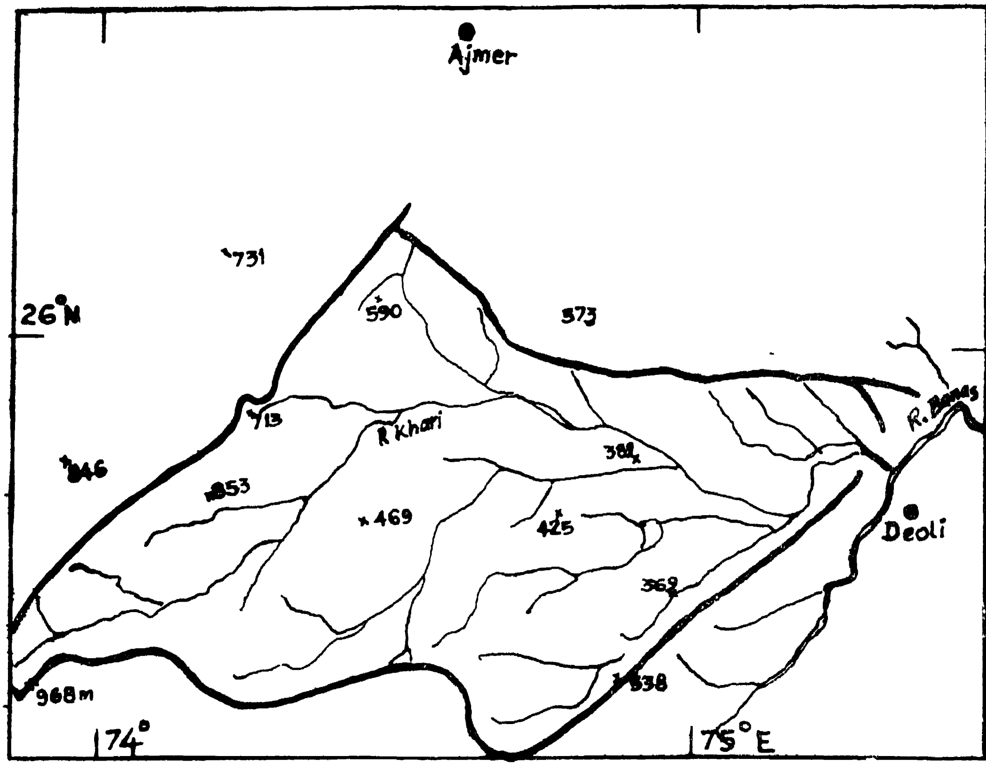


Figure 4.2 Catchment of the Khari River in east Rajasthan

Table 4.1 *Rainfall of 3" (75 mm) or more in 24 hours over Ajmer-Merwara Region in July 1943*

Stations	15	16	20	21	22	29	30
Ajmer	148						
Kekri*	81				109		
Pisangan		113					
Jawaja		81			108		
Sawar				127			
Goela					91		
Beawar					81		
Todgarh*					122	88	327
Shapura* (Bhilwar Dist)			83			108	

*Raingauge station in the catchment of the Khari (Banas tributary)

31 July 1943 was as much as 79 mm (I.Met.D. 1943). A state raingauge at Todgarh in Ajmer-Merwara had also recorded 327 mm on 30th

4 Flood Damage

The following extract from the well-known newspaper entitled "The Times of India" published on 10 August 1943 about these catastrophic floods would be of interest :

> "On the western side of India, disaster has overtaken the heart of Rajasthan, famous in India's annals for many things but not for floods. Rajputana's annual rainfall is normally about 19 inches; the phenomenal figure of about 50 inches experienced in one day in the hills of Mewar and Merwara caused an unprecedented flood in the river Khari, which runs along the south-eastern corner of Ajmer-Merwara. The devastation is described as without parallel in the history of Rajputana, that land of chivalry and romance. About fifty villages were devastat, leading to a loss of life at present estimated at about 5000. According to the Chief Commissioner of Ajmer-Merwara* the small industrial town of Vijainagar, with a population of about 7000, lost more than half its inhabitants Rajputana is ill-provided against floods of this type, which breached a whole series of bunds and tanks unaccustomed to torrential waters".

CASE No. 5

CATASTROPHIC FLOODS IN THE RIVERS IN PUNJAB (I) AND SEVERE FLOODS IN THE JHELUM IN SEPTEMBER, 1950

1. Introduction

This case is of extraordinary scientific interest not only from the point of view of the floods which developed in the rivers in Punjab (I) and in the Kashmir Valley but also because it was responsible for phenomenally heavy rainfall in North Gujarat and Southeast Rajasthan.

2. Hydrological Data

According to Uppal (1956) the peak-discharge in the river Ravi above Madhopur Head works in 1950 was 8600 cumecs (rounded off to hundreds) between 17th and 21st September, 1950. Likewise, the peak-discharge in the Sutlej above Ferozepur Headworks was 10200 cumecs on 21 September, 1950. The Director, Central

*Ajmer-Merwara was the area in Rajputana (now known as Rajasthan) which was completely under the control of the British in pre-Independent India under a Chief Commissioner. The other territories were referred to as "Native States". The latter were politically under Indian Princes.

Water Commission, Government of India, has estimated that the peak-discharge in the September 1950 floods in the Jhelum at Sangam (about 70 Kilometers from Srinagar) was about 80000 cusecs (2270 cumecs approximately). No data in respect of the discharge in the Beas in these floods are available

3 Large Scale Synoptic Situation

The author is unable to make a detailed analysis of the large scale synoptic situation over Punjab (I) and the Kashmir Valley for want of high level upper air data. The conclusions presented here in respect of these regions are based more or less on the study of similar cases in later years for which fairly adequate upper air data were available.

The floods were associated with a depression which developed in the Bay of Bengal on 12 September and intensified into a cyclonic storm of small extent during the course of the same day It crossed the Orissa Coast to the south of Balasore on the night of 13th. After crossing the coast, it moved to the central parts of the country as a deep depression and began to recurve northeastwards on 16th September. It finally broke up over the Punjab-Kumaon hills on 20 September. The track of this cyclonic disturbance in relation to the catchment of the Jhelum, Ravi, Beas, Sutlej and other rivers in Punjab (I) may be seen in Figure 5 1.

3.1. Synoptic Situation before Recurvature of the Depression Towards Northeast

Figures 5.2 and 5.3 show the 1730 IST surface charts of 16 September 1950 and 1430 IST upper-wind chart for 1.5 km. on the same day, as published in the Indian Daily Weather Report. Figure 5.4 shows the pressure departure from normal at 0830 IST on the morning of 16 September. Note particularly the dead northerly 25 knot winds over Udaipur (Southeast Rajasthan) and northnortheasterly 25 knot winds over Ahmedabad at 1.5 km on 16 September. These were deflected monsoon winds from the Bay of Bengal. It is interesting to see that, not even a drop of rain had fallen over Ahmedabad between 0830 and 1730 IST on 16th September. And yet, between 1730 IST of 16th and 0830 IST on 17th, there was a rainfall of as much as 255 mm over that city. The rainfall continued between 0830 and 1730 IST of 17th when another 256 mm. of rainfall has occurred over that city. The Observatory at the Ahmedbad Airport had recorded 533 mm of rain during the 24 hours ending 1730 IST on 17th. The Ahmedabad city had recorded 457 mm of rain during the same period. The rainfall was the heaviest recorded at that station during the previous 57 years. Mount Abu reported a rainfall of about 460 mm in 24 hours on the 18th morning. *The occurrence of such heavy rainfall can certainly be forecast well-ahead as we have seen the same pattern of wind-flow far from the central region of the monsoon depression on a large number of occasions in the past.* It is not however possible in the present state of our knowledge to forecast the amount of rainfall on a quantitative basis. Intensive meso-scale studies with a dense network of self-recording raingauges

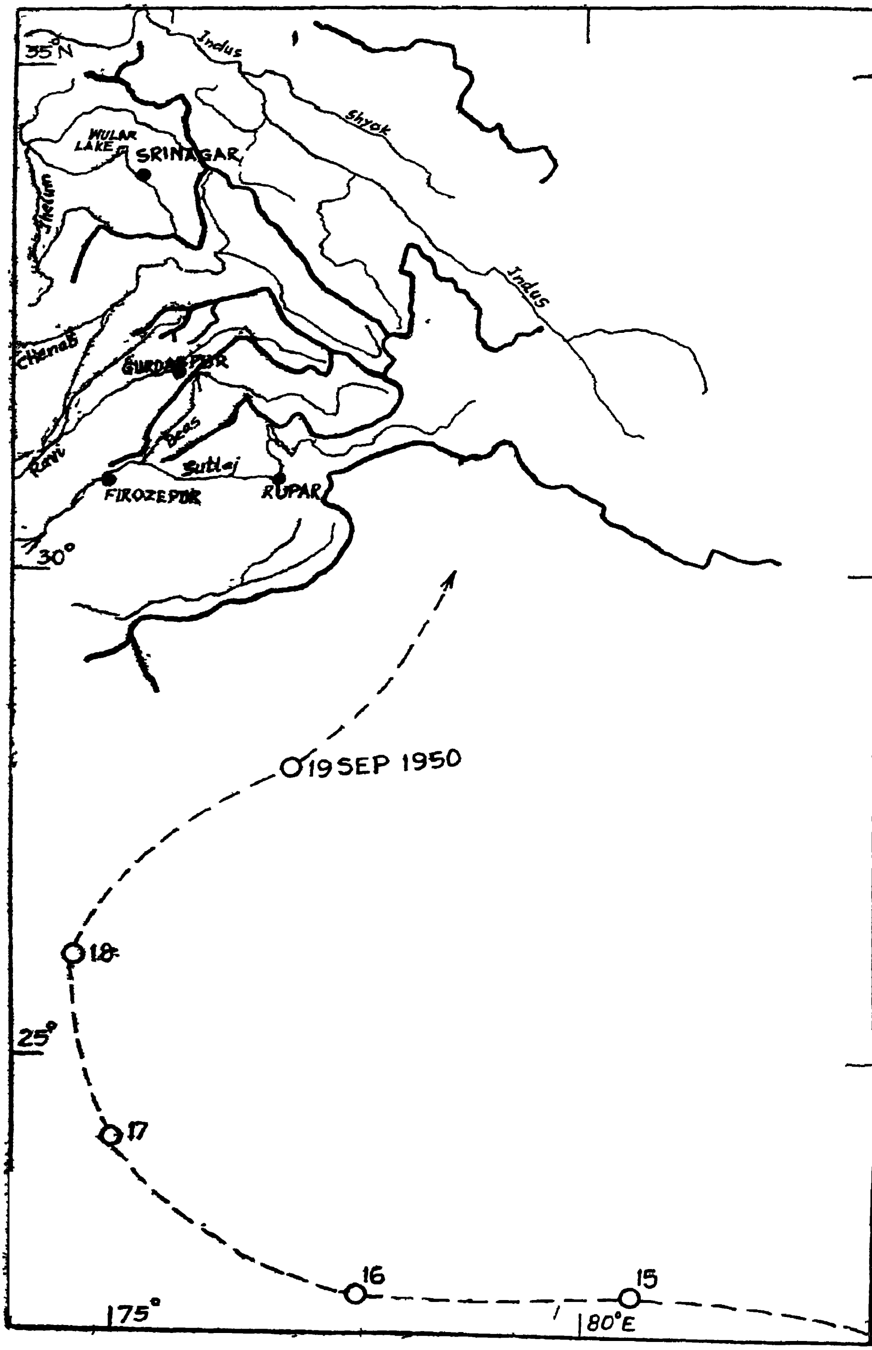


Figure 5.1 Track of Bay of Bengal Depression 12-19 Sep 1950 and Catchments of the Jhelum, Chenab, Ravi, Beas & Sutlej

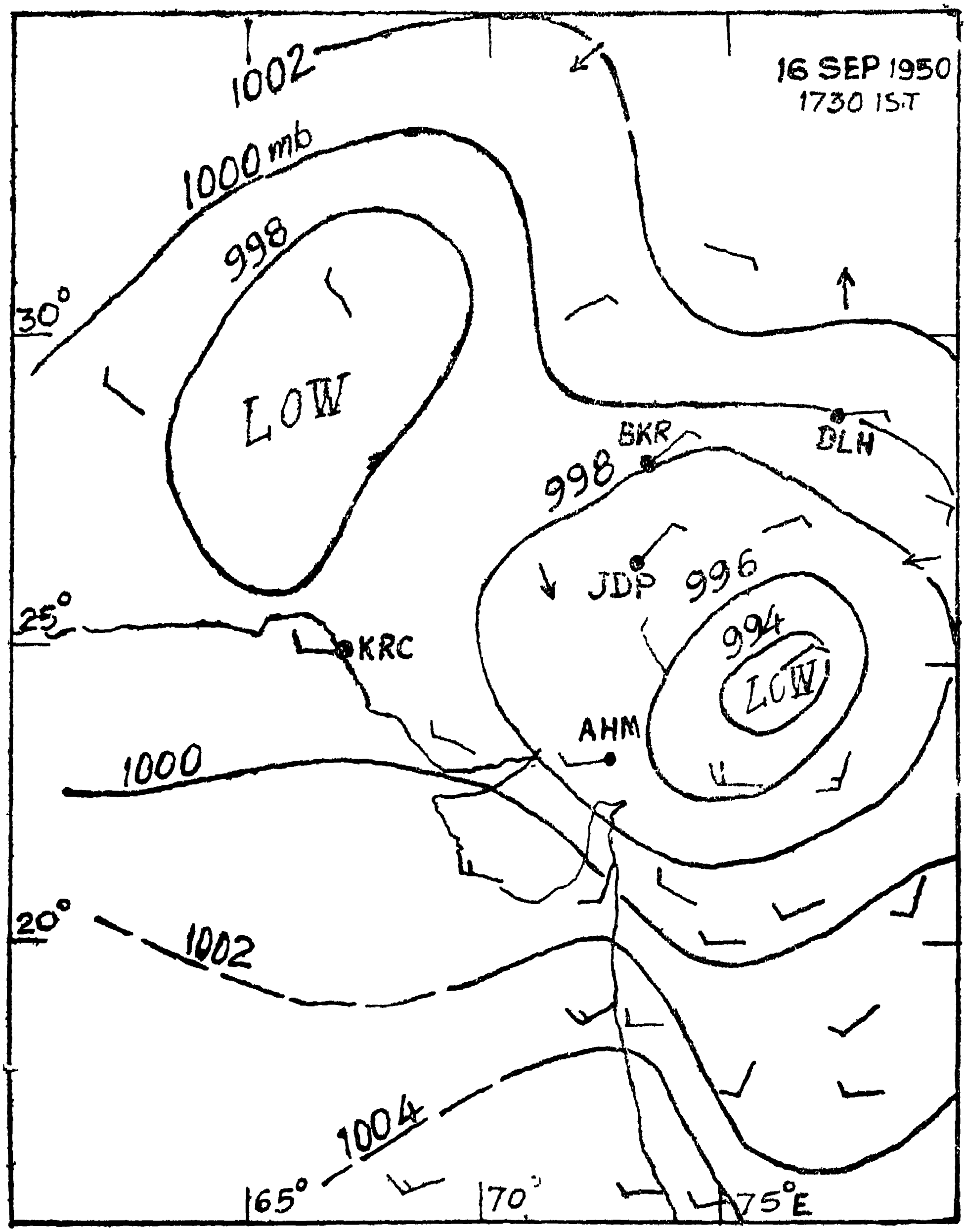


Figure 5.2 Sea-Level Isobars & Winds

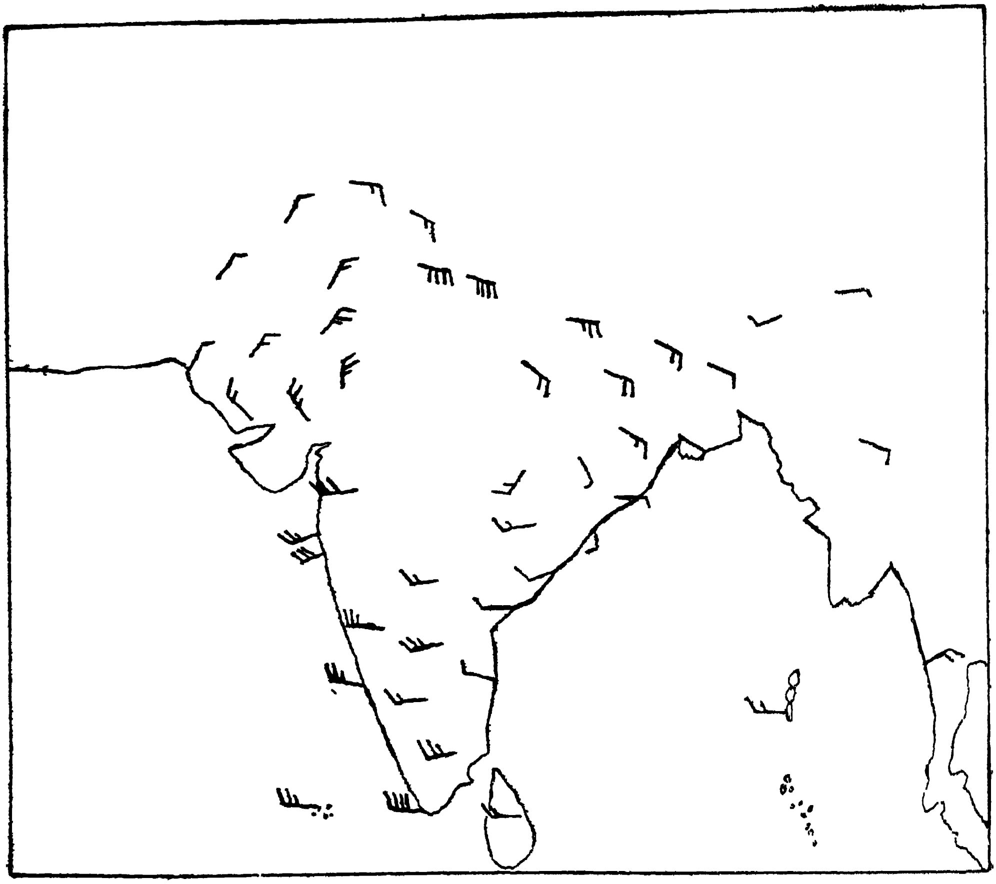


Figure 5.3 Winds at 1.5 km Above sea level 1430 NRS IST 16 Sep 1950

and other instruments besides more radio-wind stations may help us to attempt quantitative prediction of such heavy precipitation.

3.2 Synopic Situation after Recurvature of the Depression towards Northeast

Figure 5.5 shows the upper winds at 7 5 at 9 0 km levels on 19 September 1950. On the basis of the available winds, the author has delineated a deformation field with superposed anticyclonic rotation (Petterssen, 1940).

In the lobes in which wind-observations are reasonably adequate, the streamlines have been drawn as continuous lines. In the lobes in which observations are inadequate, the streamlines have been drawn as dashed lines. The track of the monsoon depression between 17 and 19 September has been shown as a continuous thick line on the diagram. The track between 18 and 19 September roughly follows the streamlines which may be taken to represent the steering field. It is difficult to

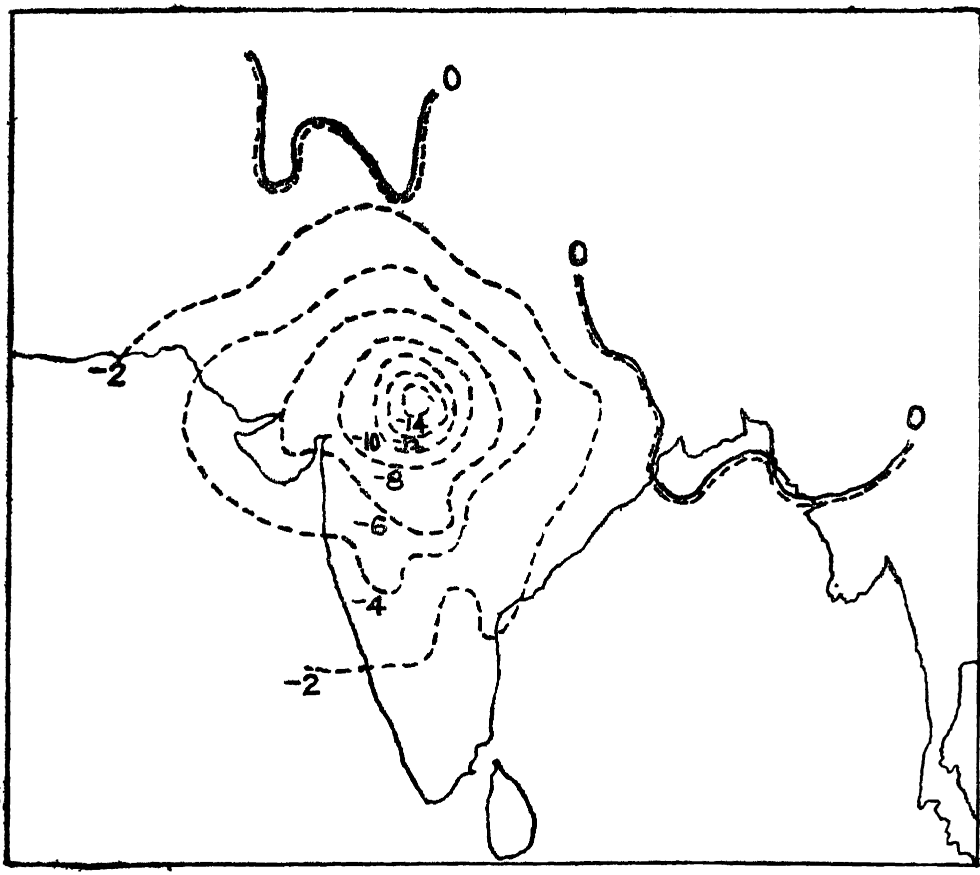


Figure 5.4 Departure of 0830 HRS Pressuke from Normal 16 Sep 1950

expect better agreement between the track of the depression and the steering field on account of the very poor network of observations available at these high levels in 1950.

We can therefore note from the above, why the monsoon depression recurve northeastwards and how the high level divergence could have contributed to the heavy rainfall and consequent floods in the Western Himalayan rivers.

4. Rainfall Analysis

Table 5.1 shows rainfall exceeding 5″ (127 mm) or more in 24 hours between 17th and 22nd September 1950. It is important to remember in this connection that even prior to the movement of the depression in the second half of September 1950, the level of water in the rivers in Punjab (I) and Kashmir (I. Met D. 1950) must have been quite high on account of the heavy antecedent precipitation during the first half of the month.

Upperwinds & Streamlines 19 Sept. 1950
7.5 km & 9.0 km. 0700 IST

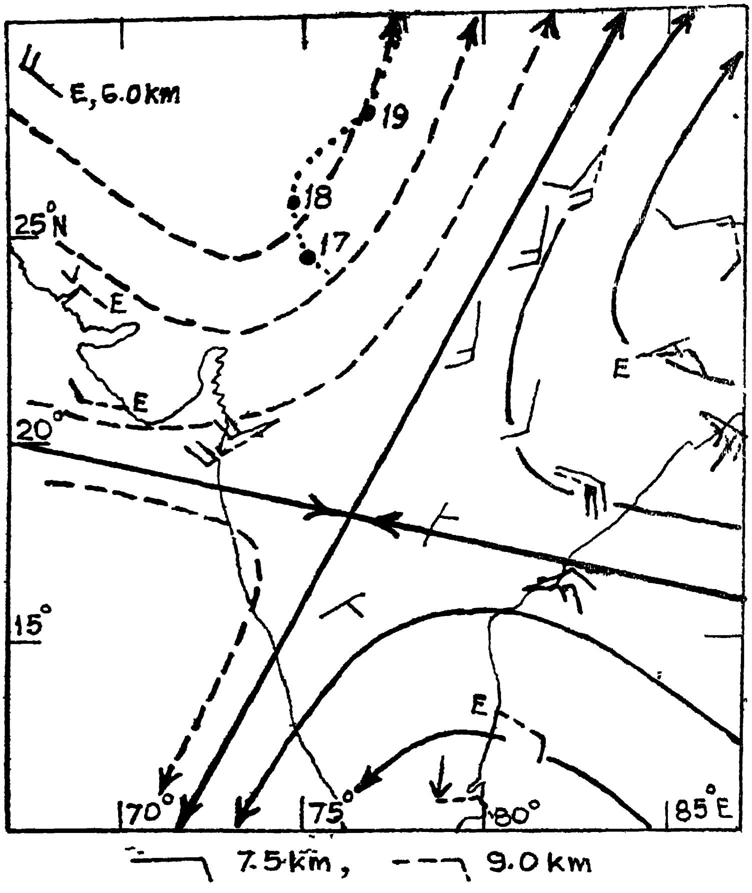


Figure 5.5. Deformation Puls Anticyclonic Rotation-●-Position of Depression Centre

5. Flood Damage

Consequent on these developments, there was heavy devastation along and near the track of the depression. Rail and telegraph communications were interrupted and hundreds of houses were damaged in North Gujarat and Rajasthan due to the heavy rains. The worst affected areas in Rajasthan were Udaipur and Bikaner where more than 20 persons were reported to have been killed. Extensive damage was also caused to property and crops by the floods in the Punjab (I) particularly in Amritsar, Gurudaspur, Hoshiarpur, Jullundur, Ferozepur and Ludhiana districts. Nearly 8½ lakhs of acreas of cultivated lands were reported to have been affected by the floods. Over 2 lakhs of houses had fallen or were damaged and about seventy persons perished under fallen roofs. Rail and road communications were seriously dislocated.

Table 5.1. *Rainfall of 5″ (127 mm) or more in 24 hours (ending at 08 hours I S.T.) over the Sutlej, Beas, Chenab and Jhehm in September 1950*

THE SUTLEJ

District	Station	3	4	16	17	18	19	20
Jullundur	Jullundur	136			178			
—Do—	Nakodar			176	249			
Ludhiana	Jagraon				172	434		
Ferozepur	Moga			170	127			
—Do—	Zira				302			
—Do—	Ferozepur		884		147			
—Do—	Jaimalwala				191			

THE BEAS

District	Station	3	4	16	17	18	19	20
Kangra	Dharmsala (Upper)		134			127		
Gurdaspur	Pathankot	156	192					
—Do—	Batala	220	156			171		
—Do—	Tibra		385			231		
Amritsar	Patti					137		

THE RAVI

District	Station	3	4	16	17	18	19	20
Gurdaspur	Gurdaspur	127	136			142		
—Do—	Dalhousie		183			138	148	
Kathua	Kathua	135			132			

THE CHENAB

District	Station	3	4	16	17	18	19	20
Jammu	Jammu					184		142
Udhampur	Udhampur					127		
—Do—	Kishtwar						127	127
—Do—	Ramnagar	155				223	195	199

THE JHELUM

District	Station	3	4	16	17	18	19	20
Southern Anantnag	Durroo					149		

Many villages were isolated for a number of days and food had to be dropped by air to the marooned people in the heavily flooded areas. In Kashmir, according to authoritative sources, the losses were very heavy. There were as many as 35 breaches in the banks of the Jhelum between Sangam and Shadipur (Srinagar and its environs). As the heavy rainfall was very extensive, the floods in the Veshau and Rambiara synchronised with the flood in the Jhelum river. The Rambiara breached its left bank and inundated the Kashmir valley on the left side of the river. All the nullahs swelled up considerably. The bunds on both sides of the river, the majority of which were on the left side, were over-topped and breached at a large number of places inundating the valley and inflicting heavy loss on crops, roads and buildings. In all, rice-paddy worth 70 lakhs of rupees was reported to have been destroyed by the floods in the Kashmir valley.

CASE No. 6

CATASTROPHIC FLOODS IN THE KOSI IN JULY AND AUGUST 1954

1. Introduction—A Historical Survey

The catastrophic floods in the Kosi in July and August 1954 are very important cases in our monograph. They are especially so, as there have been conflicting statements in the available literature regarding the values of the peak-discharges and the relative degrees of severity of the floods in the two cases. We shall therefore go into these two cases in greater detail than we have so far done in other cases.

There is indisputable observational evidence to show that the mansoon trough shifts to the foot of the Himalayas during Breaks in the monsoon. However, as the present writer had pointed out with a large number of synoptic illustrations (Ramaswamy 1958), the difference in the positions of the monsoon trough at sea-level between situations of Breaks in the monsoon and of Active monsoon, is far too small to account for the very large variations in the distribution and amounts of rainfall in these two diametrically opposite type of situations. Obviously, therefore, some other factors play a major role in such developments and which are indirectly reflected in the shifting of the monsoon trough to the foot of the Himalayas and possibly even of its annihilation at the lowest levels in the troposphere. Rao Y. P. (1976) has also very ably brought out this point although in a somewhat different way.

In the writer's paper referred to above and in a subsequent paper (Ramaswamy. 1962) the author has shown with a number of synoptic illustrations that large-scale breaks in the monsoon are essentially a phenomenon of interaction between middle and low latitudes. In such situations, the middle latitude systems extend into northern India remain quasi-stationary or move slowly eastwards. They are best seen at the 500 mb level which lies just above the mean altitude of 4.3 km of the Tibetan plateau Consequent on the intrusion of the westerly circulation (and which will be seen on the weather map as "Waves in the Westerlies" or "Western

Disturbances") the winds along the foot of the Himalayas on the Indian side become westerly at the 850 mb level and the easterlies disappear over the Gangetic plain. In fact, the disappearance of the easterlies on the sea-level charts on the Indian side of the Himalayas has been used by Ramamurthy, K (1969), as a criterion for the declaration of "Break in the Monsoon".

At the 500 mb level (approximately 5.8 km level over India in the monsoon period), in the Northern Hemisphere map, the intrusion of the westerly circulation is seen as a large-amplitude wave-trough (connected with low-index circulation in the middle latitude westerlies). By studying vectorial differences between the basic flow and the actual winds during such breaks (weak monsoon situations), Ramamurthi (1972) has shown that the westerlies intrude into northern India practically throughout the troposphere. The region of the Nepal Himalayas and the submontane regions on the Indian side often lie ahead of the 500 mb trough which region, broadly speaking (Ramaswamy, 1956) can be referred to as a region of high-level divergence. The monsoon air in the lower troposphere which persists as a monsoon airmass (with minor modifications in the properties) is "pulled up" by the high level divergence. Consequently, the latter contributes to heavy or very heavy rainfall over Nepal Himalayas, in the submontane districts of Bihar and further eastwards. This is of course, in addition to orographic effect of the Himalayas.

2. Large-scale Synoptic Aspects of the Kosi Floods in August 1954

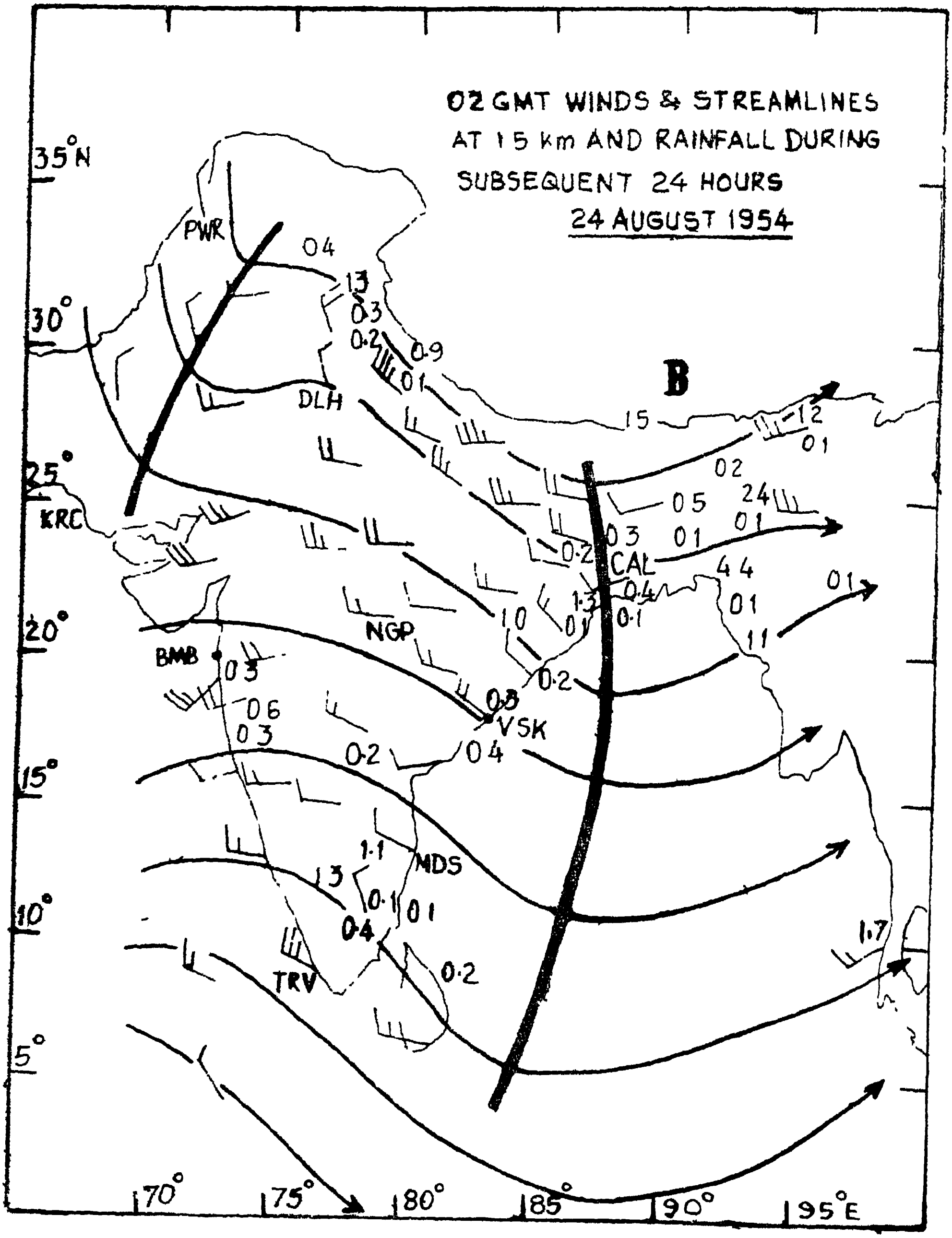
A situation of the type described above arose in August 1954 and led to severe floods in the Kosi. Figure 6.1 shows 1.5 km level (850 mb) winds and streamlines on 24th August 1954. Figure 6.2* shows the mean flow pattern at the 500 mb level on the same day and Figure 6 3** shows the 500 mb level during the period 19-25 August 1954 Figure 6.4 shows the mean zonal wind components over Calcutta during the break conditions between 19th and 25th August 1954. The intrusion of the westerly circulation upto very high levels during breaks can be clearly seen in Figure 6.4 also, although indirectly. Figure 6.5 shows the mean 700 mb flow pattern to the north of India during August 1954. This diagram has been reproduced from the map published by the Extended Forecast Division of the U. S. Weather Bureau (Winston, 1954) All these diagrams are in striking contrast to the synoptic diagrams published in the same paper (Ramaswamy 1958) relating to an active monsoon situation (not reproduced in the monograph)

3. Hydrometeorological Aspects of the Kosi Floods in August 1954

The hydrometeorological aspects of the same situation in the Kosi have been studied by Dhar and Narayanan (1966). Figure 6.6 is a reproduction of their storm isohyetal map for their 4-day rainstorm period 22-25 August 1954.

*The break in August 1954 was studied by the author as early as in 1956 (and published in 1958) The July 1954 situation is being studied by him for the first time now. The August 1954 situation is therefore being pressented here first.

**The 500mb level analysis (daily as well as mean) except over India and the neighbourhood are based on the West German Service printed charts, Taglicher Watter-bericht. Small shaded circles in Figs. 6 2 and 6 3, indicate the southern limit of the region for which the analyses were taken from the West German charts.



02 GMT WINDS & STREAMLINES AT 15 km AND RAINFALL DURING SUBSEQUENT 24 HOURS
24 AUGUST 1954
B
35°N
30°
25°
20°
15°
10°
5°
70°
75°
80°
85°
90°
95°E
PWR
DLH
KRC
BMB
NGP
VSK
CAL
MDS
TRV

Figure 6.1

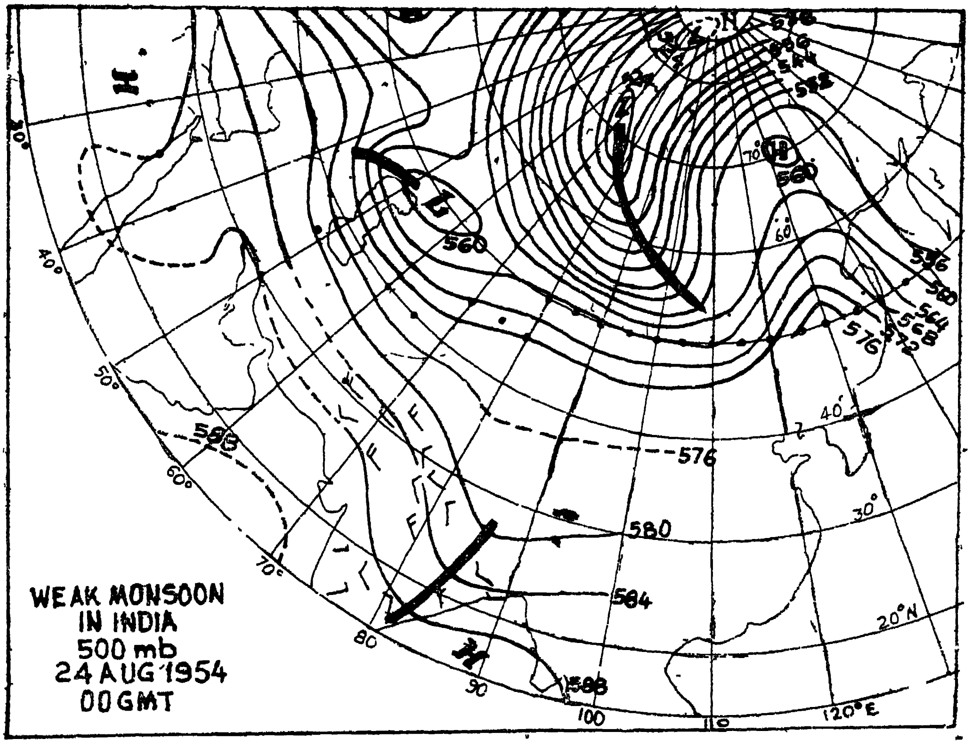


Figure 6.2

The flood-hydrograph at Sunakhambikhola (26°55'N, 87°61'E) near Barakshetra published by the same authors may be seen in Figure 6.7. Figure 6.8 shows the depth-duration curves for the period 22 to 25 August 1954 as published by them.

According to these authors, "it was not the Himalayan reach alone that was responsible for the large-scale inundation over the Indian plains". *The rainfall depths over the plains reach* (below Barakshetra) were almost equal during the 4-day rainfall to that over the Himalayan reach. This conclusion is perfectly consistent with our conclusions based on our large scale synoptic study.

Dhar and Narayanan have stated that during the period 1947-63 Kosi recorded the highest peak-discharge value of 24220 cumecs on 24 August 1954. The same figure of 24220 cumecs has also been given independently by Mookherji (1961).

4. The Catastrophic Floods in the Kosi in July 1954

Hydrological Data

Hydrological data in respect of July 1954 floods in the Kosi have been given by UNESCO in their catalogue (1976) on Very Large Floods. Extracts from their catalogue have been given in Table 6.1.

It will be seen from Table 6 1 that the peak-discharge of 17400 cumecs in the max Kosi on 27.7.54 was the highest Q_{max} among the 5 cases of Very Large Floods

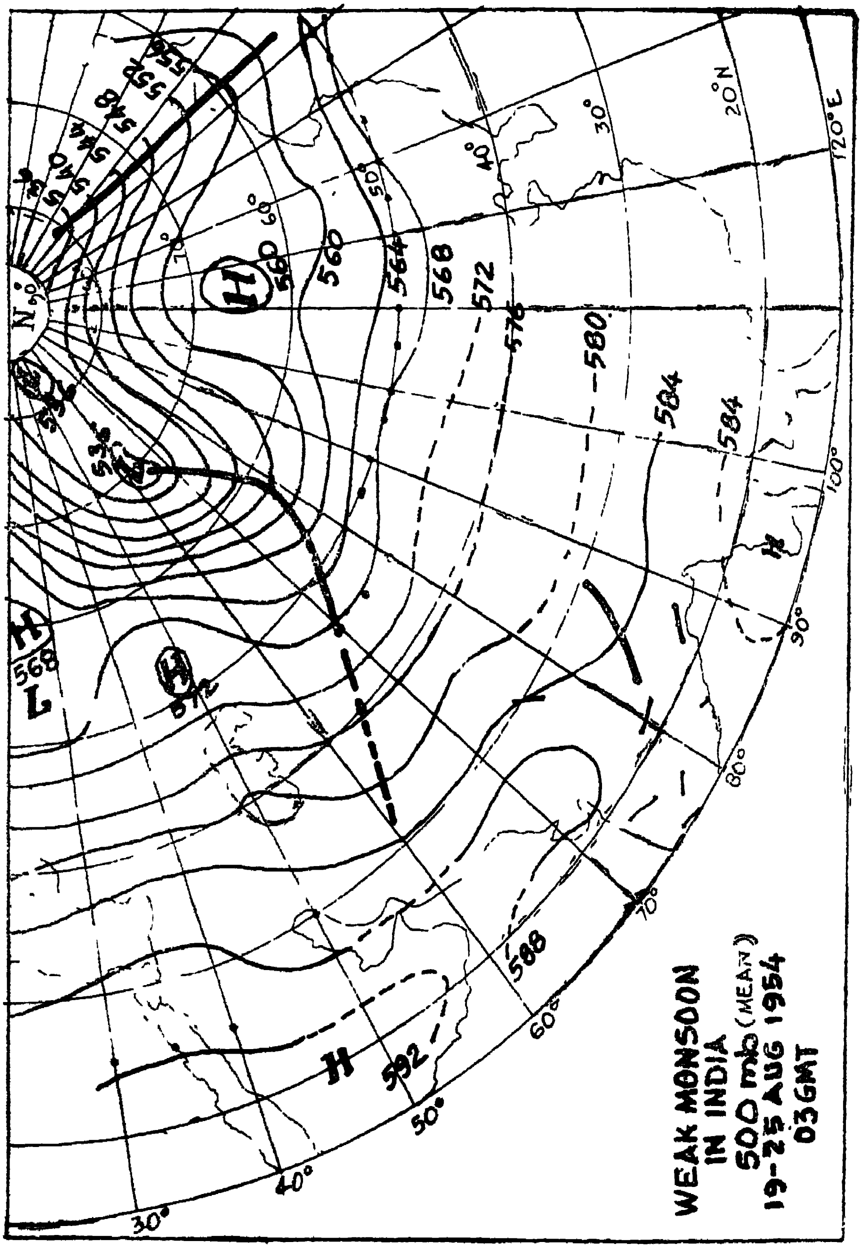


Figure 6 3

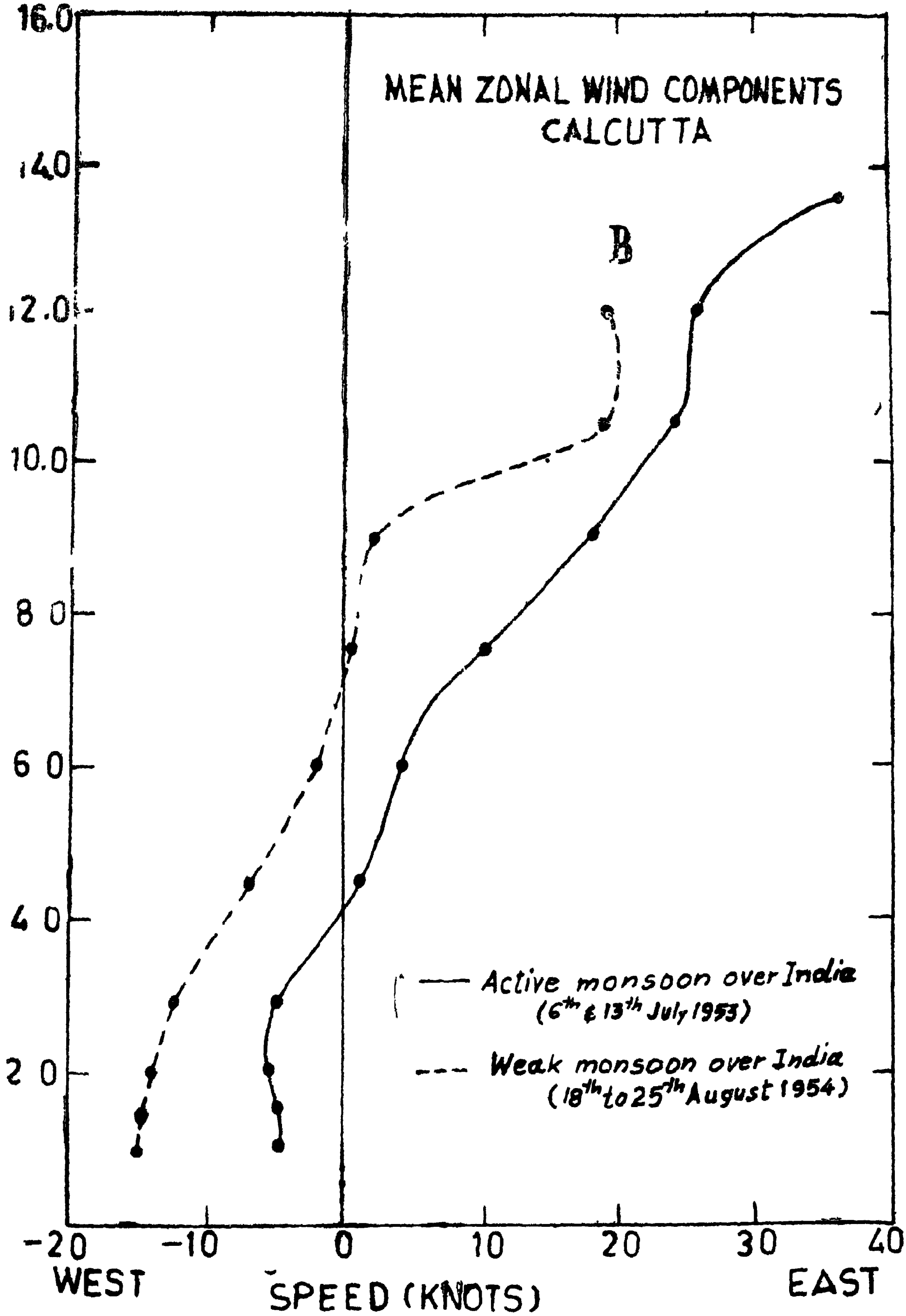

MEAN ZONAL WIND COMPONENTS
CALCUTTA
B
16.0
14.0
12.0
10.0
8 0
6 0
4 0
2 0
—— Active monsoon over India
(6th & 13th July 1953)
--- Weak monsoon over India
(18th to 25th August 1954)
−20
−10
0
10
20
30
40
WEST
SPEED (KNOTS)
EAST

Figure 6.4

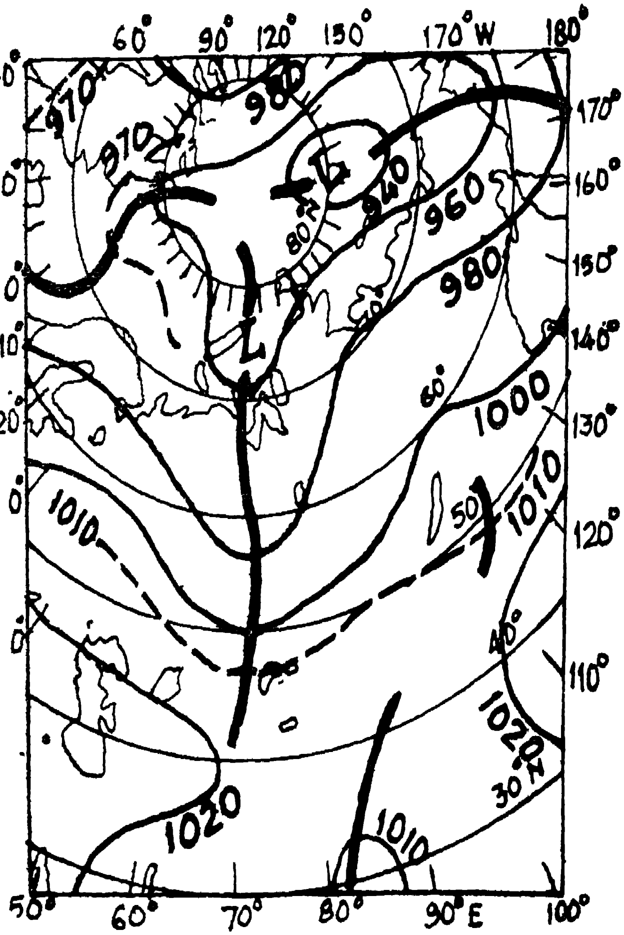


Figure 6.5 Aug. 1954 700 mb

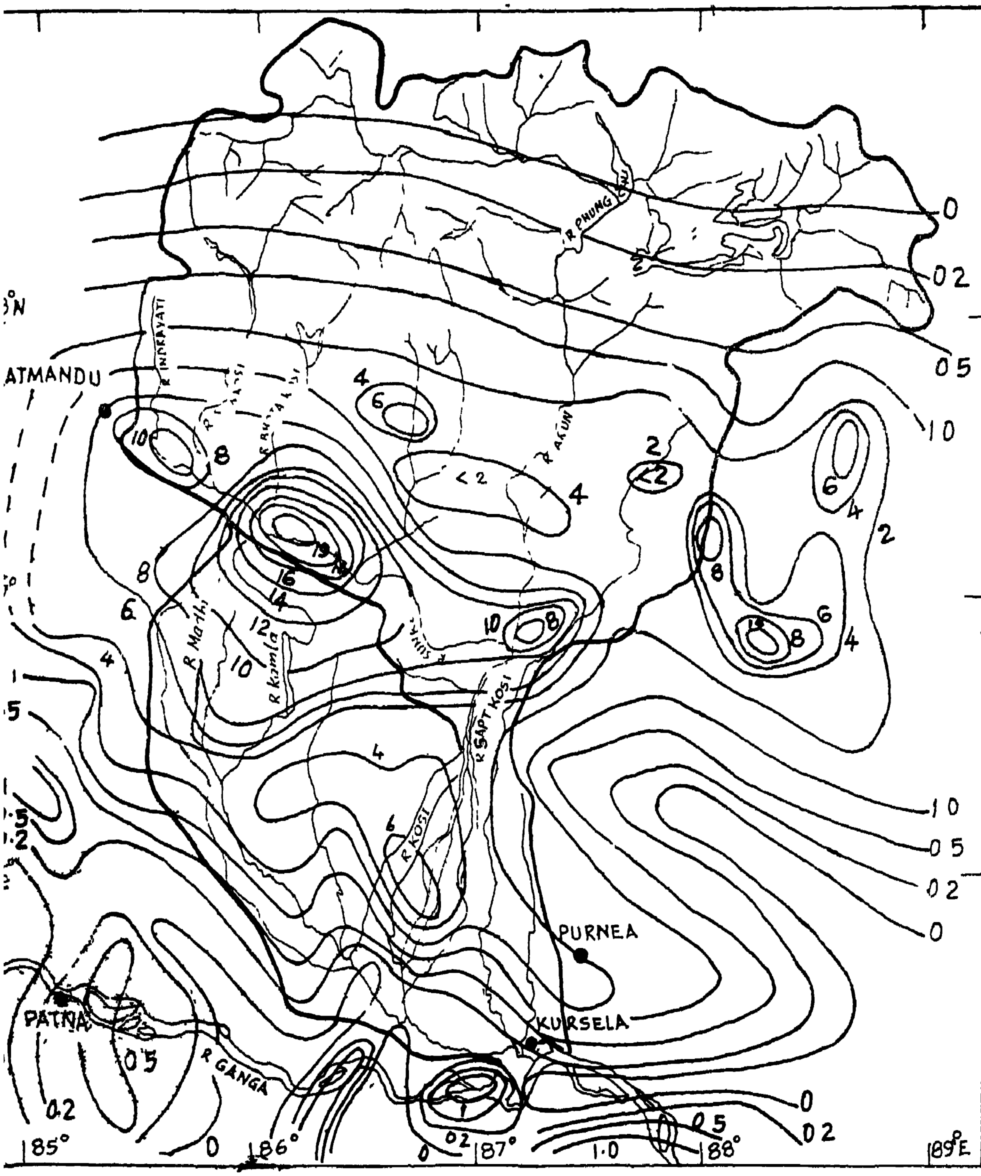


Figure 6 6 Storm 150 Hyetal Map, 22-25 Aug. 1954

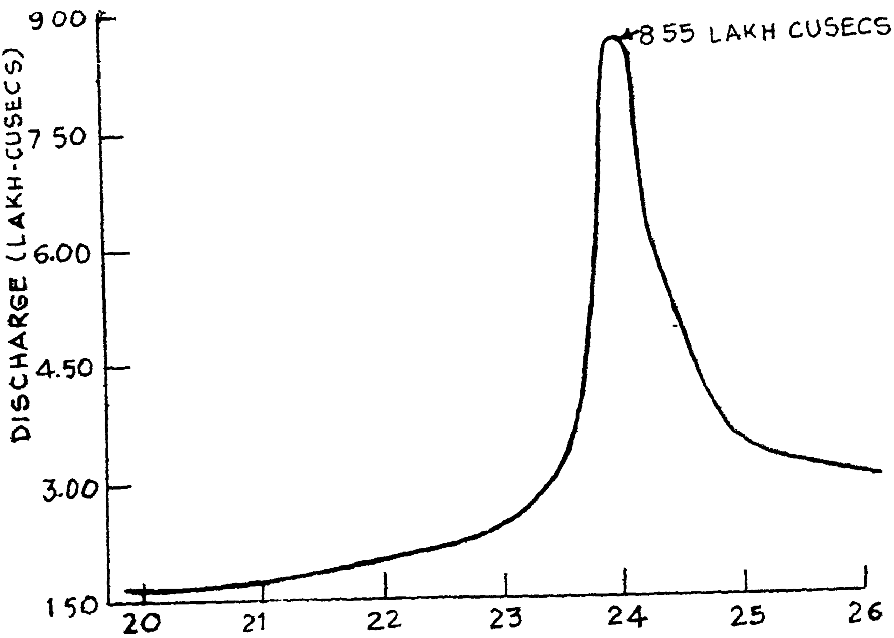


Figure 6.7 (Through the courtesy of the Editor, Indian Journal of Meteorology and Geophysics)

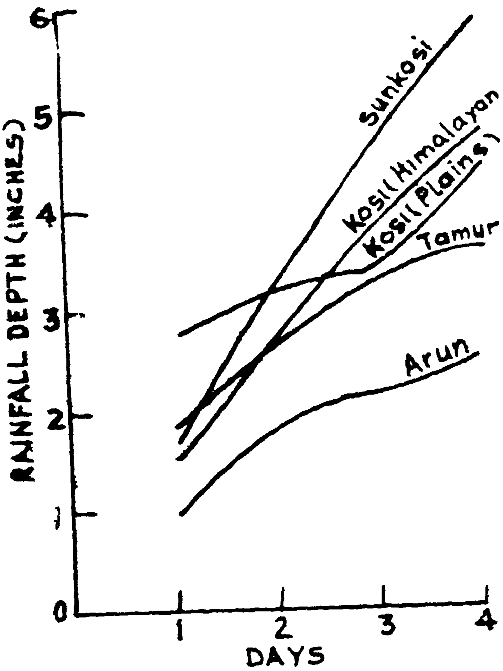


Figure 6.8

Table 6.1

Q max Peak-discharge m³/sec.	Date	h depth of run off (mm)	T_+ Total duration of the flood (Hours)	ti Time to peak (hours)	Rainfall forming flood
(4)	(5)	(6)	(7)	(8)	(15)
17400	27.7 54	74.0	328	192	499

Maximum Daily Rainfall (mm)	Date	Hourly Maximum Rainfall (mm)	Date	Antecedent pre *cipitation for* 10 days	30 days	Remarks
(17)	(18)	(19)	(20)	(21)	(22)	
80.3	26 07 54	31 0	26 07 54	276	528	

h-depth of run of f=W/Af where W is the flood volume and A is the area of the Basin ($Km^2{}_s$).

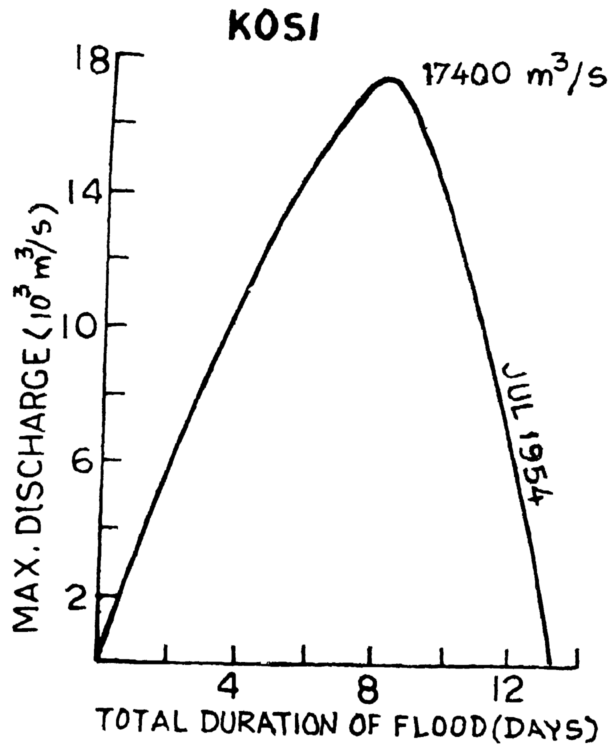


Figure 6.9

in the Kosi listed in the catalogue. The discharge value of 17400 cumecs was also the highest maximum discharge value on any particular day during the 20-year period 1947-1967 included in Table II on page 22 in the UNESCO catalogue (Annual Maximum discharges resulting from rainfall). The Flood-hydrograph based on the information contained in the UNESCO catalogue may be seen in Figure 6.9.

Table 6.1 also shows the total duration of the flood in the Kosi in July 1954. It was a little more than 13 days (328 hours) while the time to reach the peak was 8 days (192 hours). The maximum daily rainfall as well as the hourly maximum rainfall over the basin as a whole, occurred on 26 July 1954 one day before the peak-discharge occurred. Further, the figures of antecedent precipitation in 10 days as well as 30 days before the peak flood were the highest among the cases of Very Large Floods in the Kosi listed in the catalogue.

5. Large-Scale Synoptic Situation in July 1954

On the basis of the criterion that easterlies should be absent at 2000 feet a s l. along the foot of the Himalayas during breaks in the monsoon, we can state with confidence

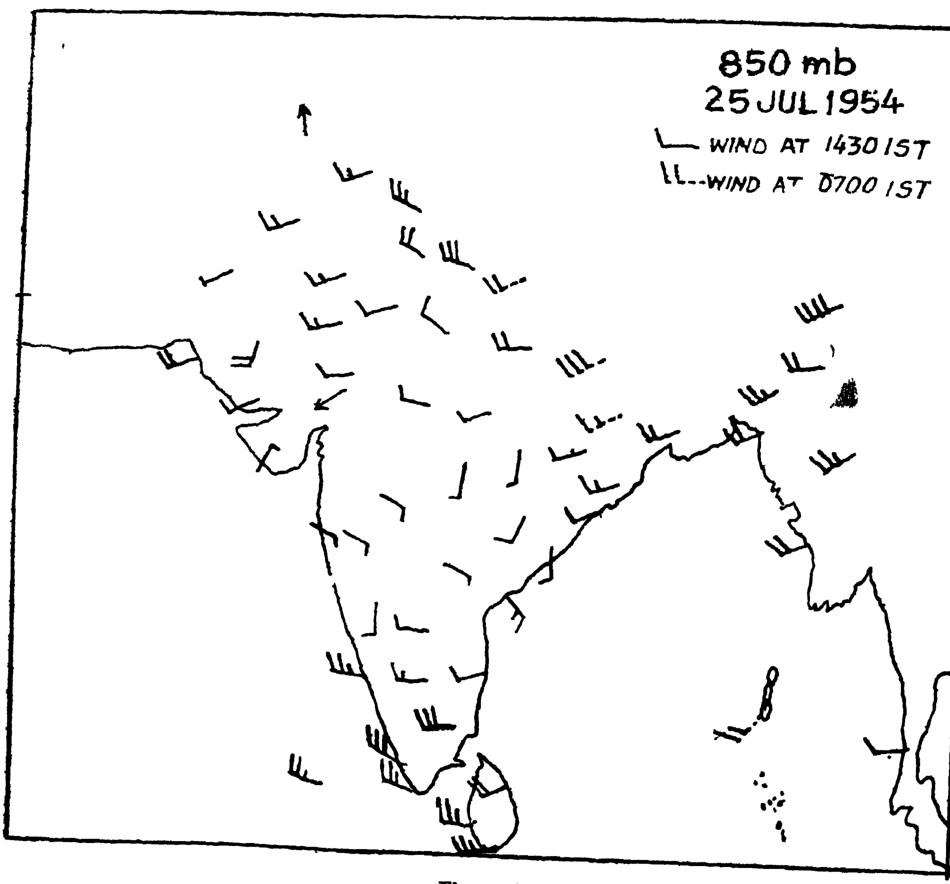


Figure 6.10

that a break-spell existed between 24 and 31 July 1954. It is interesting to see that this is just the period when the observatories in the catchment of the Kosi in Nepal Himalayas recorded heavy rainfall vide Table 6.3 in this monograph. We shall therefore present here typical synoptic charts during these break-conditions. Figure 6.10 shows the upper winds at 850 mb level (1.5 km a.s.l.) at 12 GMT on July 1954 The complete absence of the easterlies along the foot of the Himalayas on this map may be noted. The maximum heavy rainfall in the Nepal Himalayas during the break-spell was reported next morning. Figure 6.11 shows the 500 mb contour pattern at 1200 GMT on the same date i.e. on 25 July 1954. The 500 mb map is an exact reproduction from the Northern Hemisphere map published by the U.S. Weather Bureau. Their map does not contain any actual data at the 500 level over China and the neighbouring areas. Their charts therefore suffer from the same limitations as those for the August 1954 situation shown in Figures 6.2 and 6 3 Not withstanding these limitations, the 500 mb for 25 July 1954 shown in Figure 6.11 does reveal the pronounced low index circulation in the middle latitudes and the intrusion of the large amplitude trough in the westerlies into the Indian sub-continent. It is important to remember in this connection that in the 1950's the Indian radio-sonde data were not free from serious errors (Ramaswamy, 1956). Hence, considerable caution has to be exercised before the Indian radio-sonde heights are accepted at their face value and

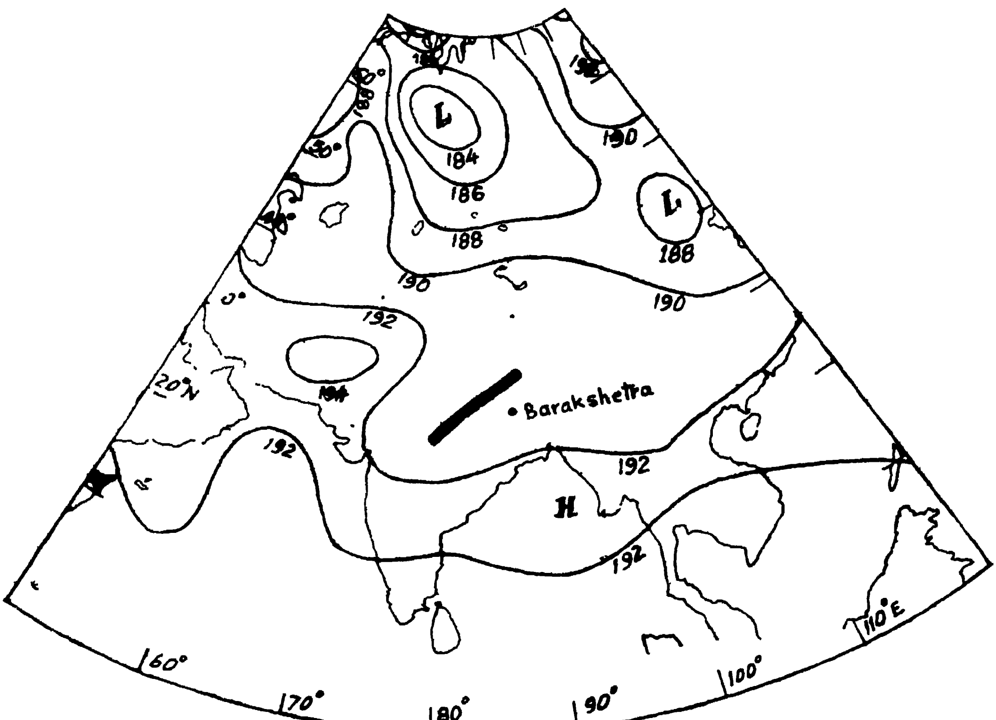


Figure 6 11

contours are drawn on the basis of these Indian radio-sonde hights. The wind data over the Indian sub-continent were however reliable enough for our present large-scale studies. The trough line on the 500 mb mp (Figure 6.11) has been drawn by us. It will be seen that the Nepal Himalayas and the Kosi catchment lie ahead of the trough-axis and that the very heavy rainfall (see section 6 below) had, broadly apeaking, occurred ahead of the axis of the trough.

Figure 6.12 shows the mean 700 mb contour pattern to the north of the Indian sub-continent in July 1954. This diagram has been reproduced from the map published by the Extended Forecast Division of the U.S. Weather Bureau (Hawkin Jr., 1954).

It is interesting to see from Figure 6.12 that :

a) a large amplitude mean trough is protruding equtorward from 75N to 30N i.e. to the southernmost latitude printed in the U.S. Weather Bureau map.

b) a mean negative height anomaly of as much as 80 feet exist between 80E and 90E and from 40N to 50N.

c) the large-amplitude trough is as marked as the one in the mean 700mb map for August 1954 vide Figure 6.5.

July 1954 700 mb

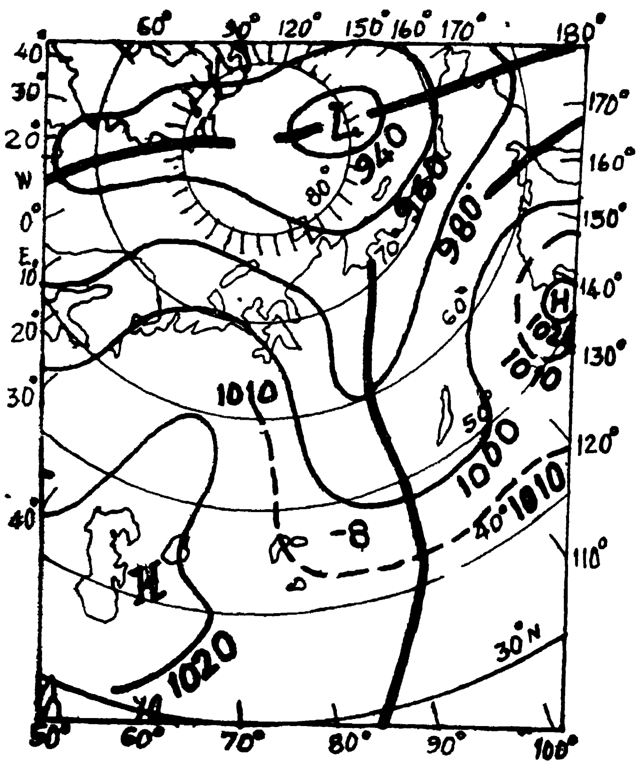


Figure 6.12

Thus the factual evidence brought out in the above paragraphs shows that from the point of view of large-scale synoptic conditions, the break-situation in July 1954 was as marked as the one in August 1954.

Figure 6.12 for July 1954 may be compared with Figure 6.5 for August 1954. It will be agreed that the mean 700 mb July 1954 contour map (to the north of India) is as favourable for heavy rainfall in the Kosi catchment as the mean 700 mb. contour map for August 1954 (to the north of India)

Figure 6.13 and 6.14 show the mean 500 mb contour maps over the Indian sub-continent as published by the India Meteorological Department (1954) for the month of August and July 1954 respectively. No one can deny that the mean 500 mb pattern for July 1954 over India was far more favourable for heavy rainfall in the Kosi catchment than the mean August 1954 pattern. And if we remember that these mean 500 mb maps are for the respective whole months and not merely for the individual specific spells of heavy rainfall in the Kosi catchment which we have studied in the earlier sections, the contrast in the large-scale mechanism which produced the disastrous floods in the Kosi in August and July 1954 becomes even more obvious.

Thus the cumulative factual evidence brought out by us shows that from the point of view of large-scale synoptic conditions, the break-situation was favourable

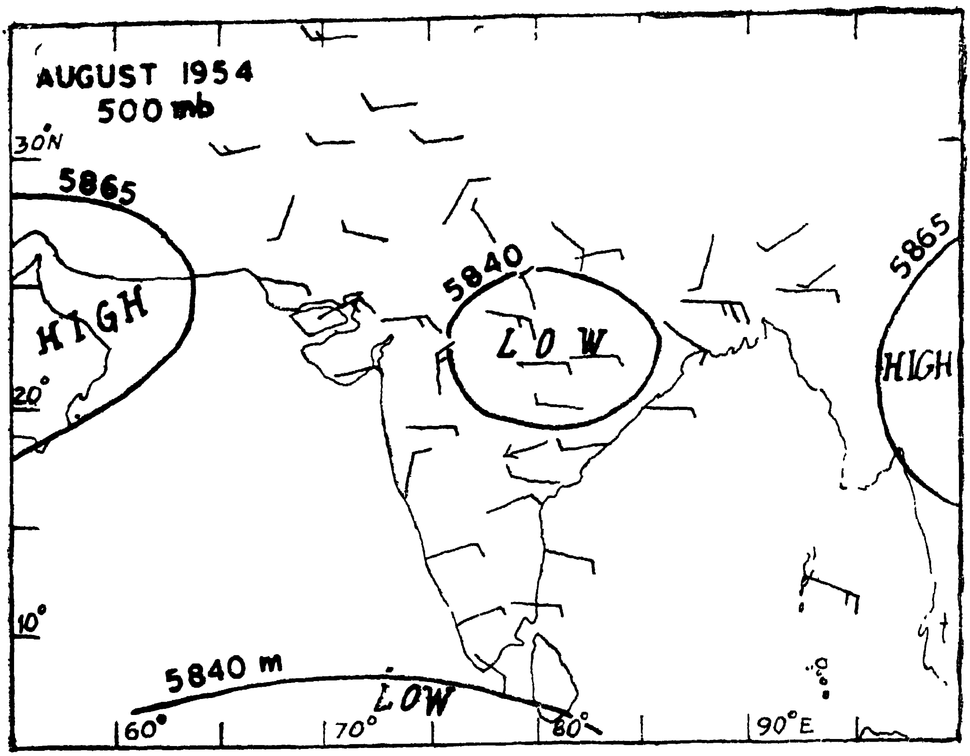


Figure 6.13 Monthly Mean Constant Pressure Chart

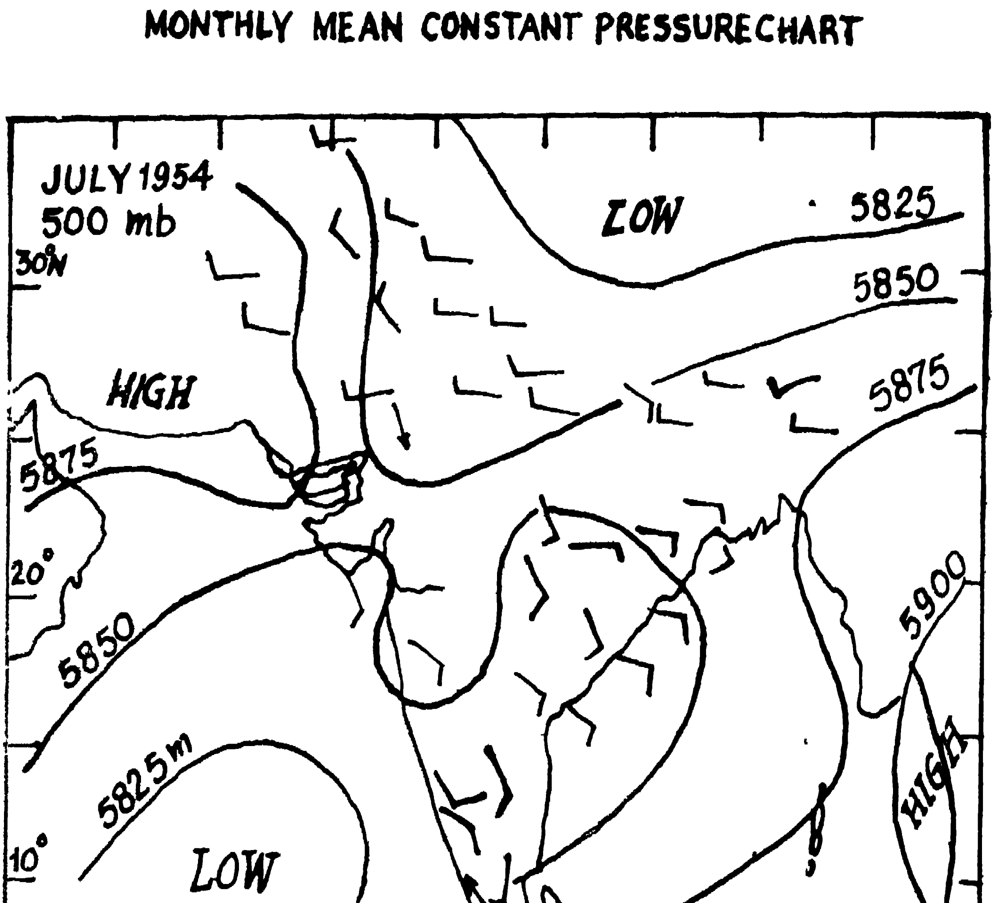

MONTHLY MEAN CONSTANT PRESSURECHART
JULY 1954
500 mb
LOW
5825
5850
5875
HIGH
30°N
5875
20°
5850
5900
5825m
HIGH
10°
LOW
60°
70°
80°
90°E

Figure 6.14

Table 6,2 *Rainfall of 75 mm or more in 24 hours over the Kosi catchment between 19-26 August, 1954.*

District	Station	19	20	21	22	23	24	25	26
Indian Region									
Muzaffarnagar	Sursand				135				
Monghyr	Gogri		132						
Saharsa	Supaul		123		174				
	Madhipura				170				
Darbhanga	Madhwapur	76			152				99
	Rosera		80						
	Madhepur			108					
	Bahera				81				
	Khajauli				81				
	Umgaon				153				
	Phulparas				102				
	Madhubani				140				80
	Laukaha								90
	Darbhanga				76				
Nepal Region									
Tamur subcatchment	Dhonkuta						185		
	Phalut						110		
Arun subcatchment									
Machuaghat							128		
Sun-Kosi sub-catchment	Dhulikhel						109	110	
	Kuruleghat						88	186	
	Okhaldunga						80	107	
	Nepalthok						76		
	Ramechop				107	222	96		
	Mynebhanjyang					115	200		89
Saptkosi sub-catchment									
	Chatra					129			
	Barahkshetra						125		
	Tribeni						114		
Kamla subcatchment	Sirha				152				203

Table 6.3 *Rainfall of 75 mm. or more in 24 hours over the Kosi catcnment between 23-31 July 1954*

Station	23	24	25	26	27	28	29	30	31
Indian Region :									
Mzaffarpur Dt.									
Sursand			81						
Darbhanga Dt.									
Khutaunoe		89							
Laukhaha			114						
Bahera			79						
Rosra			114	78					
Ladania			112			93			
Modhwapur				79	89	89			102
Nepal Region									
Tamur sub-catchment									
Dhankuta			102						
Phalut			96	107					
Taplethok		76							
Arun sub-catchment									
Machuaghat			168	110					
Bhojpur									100
Sun-Kosi sub-catchment									
Aisyalukharka			89						
Chautara				99					
Dhulikhel				147	176	125			
Son-kosi sub-catchment									
Kuruleghat		213		162	106				
Manebhnnjyang				218	109				
Ramecoap			198	228					
Okhaldunga				143					
Ghumthang	114	171	151	114	177	182	164		
Sapt Kosi sub-catchment									
Barahkshetra		136	171	155					
Chatra		98	157	168		141			143
Dharan Bazar	76	185	157	86	81	140		134	165
Tribeni			165	146					
Sun-Kosi sub-catchment									
Mandan			95	100	191				
Kamla snb-catchment									
Sirha			140	85	82				

in July 1954, if not more favourable than in August 1954, for the catastrophic floods in the Kosi catchment.

One of the contributory factors to the heavier rainfall on a large number days in July 1954 (see section 6 below) might be that, in that month, there was additional lower tropospheric convergence (a very unusual feature as pointed out by Parthasarathy (1954)) associated with the direct incursion of the monsoon stream from the Bay of Bengal.

6. Rainfall Analysis in the Break-spells in July 1954 and August 1954

Tables 6.2 and 6.3 prepared by us show the number of occasions of 75 mm of more in 24 hours in the Kosi cotchment in August and July 1954. It will be seen that heavy rainfall was more in July 1954 than in August 1954

7. Flood Damage

No separate reports of the damage caused by the Kosi alone in August 1954 and July 1954 were available to the author. However, extracts from the following reports give us a reasonably good picture of the havoc and misery coused by this river. For purpose of chronological sequence, we shall first give the description in respect of July 1954, and then of August 1954.

A. Extract from the Monthly Weather Report for July 1954 published by India Meteorological Department :

"....... ....By about this time, reports appeared in the press of floods in the river Kosi which sweeping across Saharsa and Dharbanga districts of North Bihar, affected a population of about 4 lakhs of people .. ..".

B. Extract from the monthly Weather Report for August 1954 (I. Met. D.) :

"As a result of the heavy rains in the Himalayan areas,......the Kosi,.. ......rose in spate. The floods in Bihar were again devastating."

C Extract from the paper by Parthasarathy (1954)

"........According to statements in the press, these floods in Bihar, Bengal and Assam had taken a toll of 247 lives. A total area of 25650 square miles and nearly 95 lakhs of people have been affected and a large number of cattle heads have perished. Serious damage to crops, roads, railways, bridges have occurred on a scale never experienced before.. ..... ".

CASE No. 7

CATASTROPHIC FLOODS* IN THE RAVI, BEAS, SUTLEJ, THE YAMUNA AND OTHER RIVERS IN PUNJAB (I) AND PEPSU IN OCTOBER, 1955

1. HYDROLOGICAL DATA

The following data have been extracted from a paper by Uppal and Sehgal (1966) :

Table 7 1

River	Gauge Site	Date	Gauge level (metre)	Maximum discharge (cumecs rounded off to hundreds)
Ravi	Madhopur	3/5.10.1955	12	17,500
Beas	Pong/Dera Gopipur	5 10.1955	8	8,500
Sutlej	Rupar Head Works	6.10.1955	—	10,600

N.B. These were the highest discharges in the respective rivers in the years concerned The discharge of 17,500 cumecs in the Ravi between 3 & 5 October 1955 at Madhopur was also the highest discharge which occurred in any of the rivers mentioned above, during the entire period 1922-62.

2. Synoptic Situation

The subsequent track of the cyclonic system as published in the India Weather Review 1955, Annual Weather Summary Part C may be seen in Figure. 7.1. It will be noted that the depression remained practically stationary on the 3rd and 4th* October before curving to the north. It subsequently weakened and on the morning of the 5 October it lay as a low pressure area. Its centre could not be fixed with any degree of certainty on this date. Hence none of publications of the I. Met. D. including the India Weather Review, showed or referred to any centre for this system on the

Note : This is one of the most important cases presented in this monograph. It was initially presented by the writer and his collaborator Vuddagiri Subba Rao as a Preliminary study in a symposium on "Tropical Monsoons" held at the Indian Institute of Tropical Meteorology, Pune in September 1976 (Ramaswamy and Subba Rao, 1976). The first author has since seen that the surface synoptic chart for 4 October 1955 and the upper winds at 5000 ft. a.s.l. were, for the first time, published by Parthasarathy with comments on the same. Rao, Y.P. (1976) had also later reproduced the same surface chart of 4 October 1955. The author of this monograph has however since studied this remarkable case in much greater depth. The new conclusions have been presented in Section 4.

*The I. Met. D. Atlas of Storm tracks has inadvertently omitted to show the position on the 4th by the side of 3 October. The storm track as published in the India Weather Review for 1955 Part C however shows the position on the 4th. We agree with this determination on the basis of our own study.

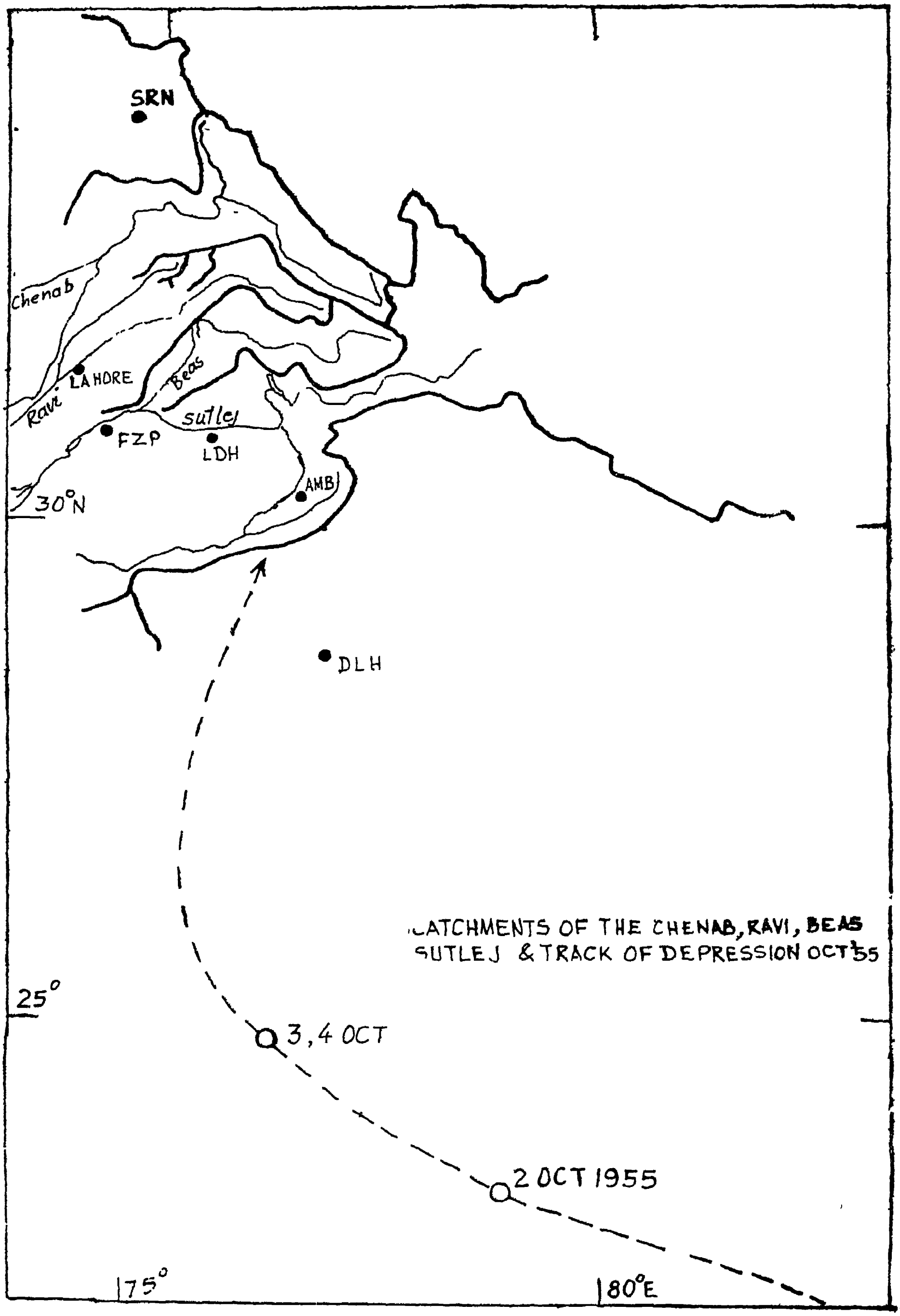

SRN
Chenab
LAHORE
Ravi
Beas
Sutlej
FZP
LDH
AMB
30°N
DLH
CATCHMENTS OF THE CHENAB, RAVI, BEAS
SUTLEJ & TRACK OF DEPRESSION OCT'55
25°
3,4 OCT
2 OCT 1955
75°
80°E

Figure 7.1

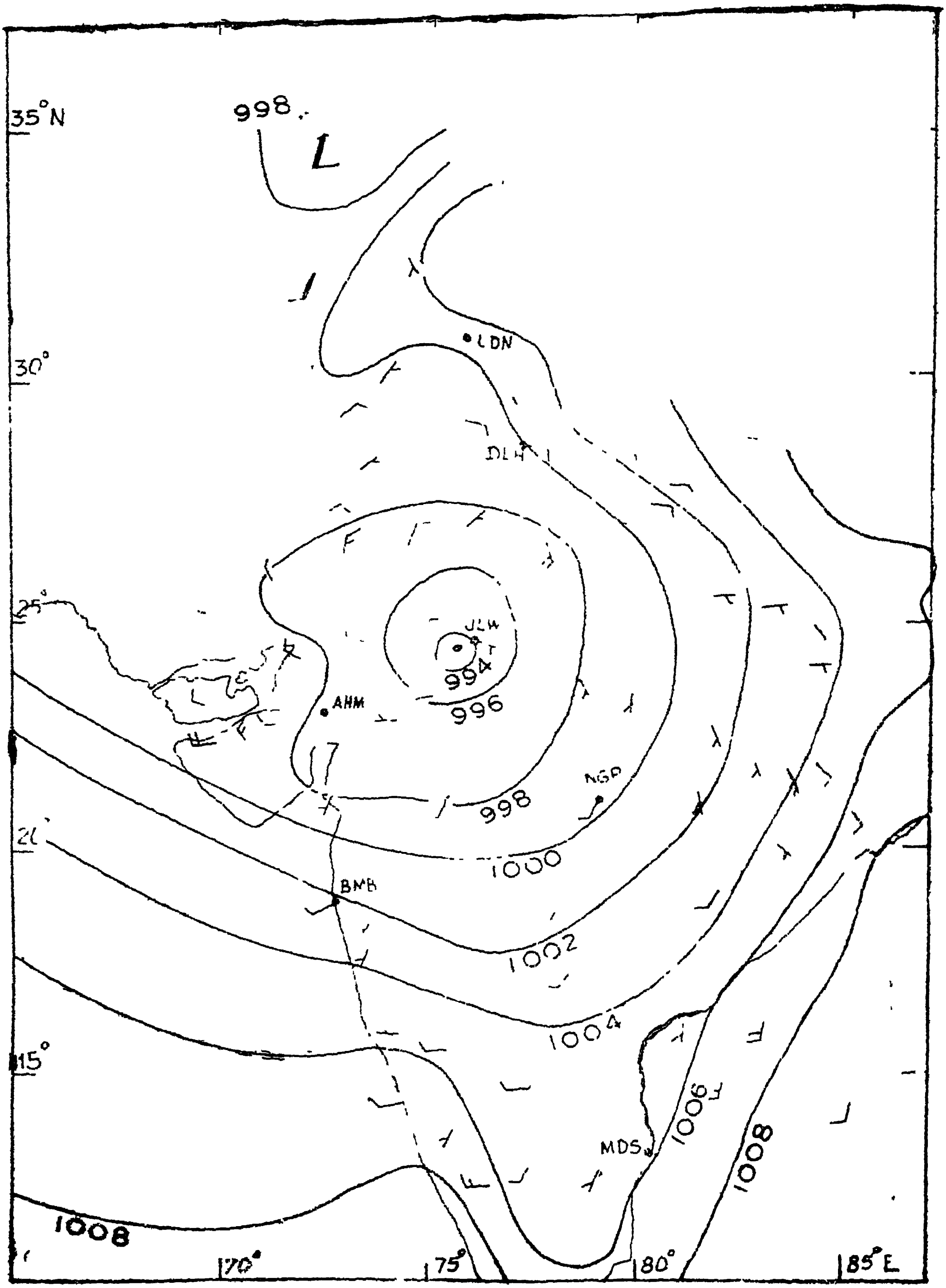


Figure 7.2 Surface Isobars and Winds 1730 Ist, 3 Oct., 1955

5th. We are therefore justified in referring to it as a Low Pressure area. The latter disappeared during the course of the next 24 hours.

Figure 7.2 shows the sea-level isobars and surface winds at 1200 hours GMT on the evening of 3 October as drawn by the author on the basis of the data available on the charts prepared at the Safdarjung Forecasting Office at New Delhi. The data-coverage on this chart was quite satisfactory. However to avoid undue congestion, only selected stations and those too showing only the surface winds, have been plotted in Eigure 7.2.

Figure 7.3 shows the isopleths of pressure-departures from sea-level at 12 GMT on 3 October i.e. corresponding to the same synoptic hour as Figure 7.2. The isopleths have been drawn by the author on the basis of the data available at the Safdarjung Forecasting Office, New Delhi.

Figure 7.4 shows the isopleths of 24 hours pressure changes at the same synoptic hour (12 GMT) on 3 October. These isopleths have also been drawn by the author.

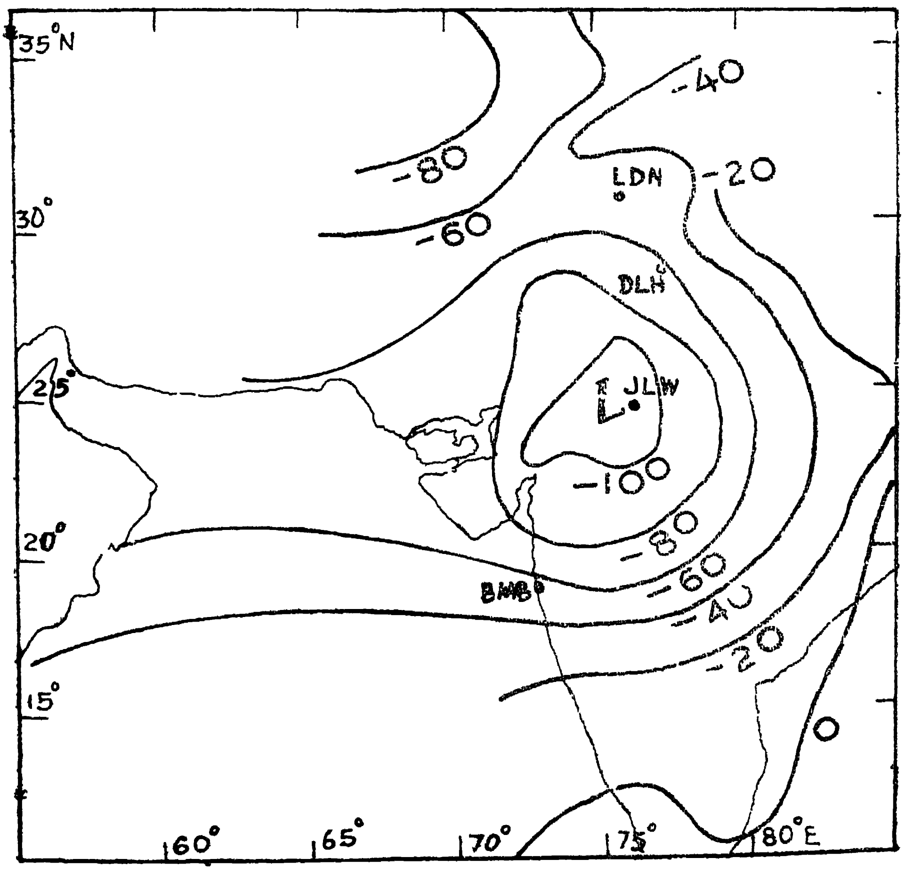


Figure 7.3 Pressure Departure from Normal 3 Oct., 1955

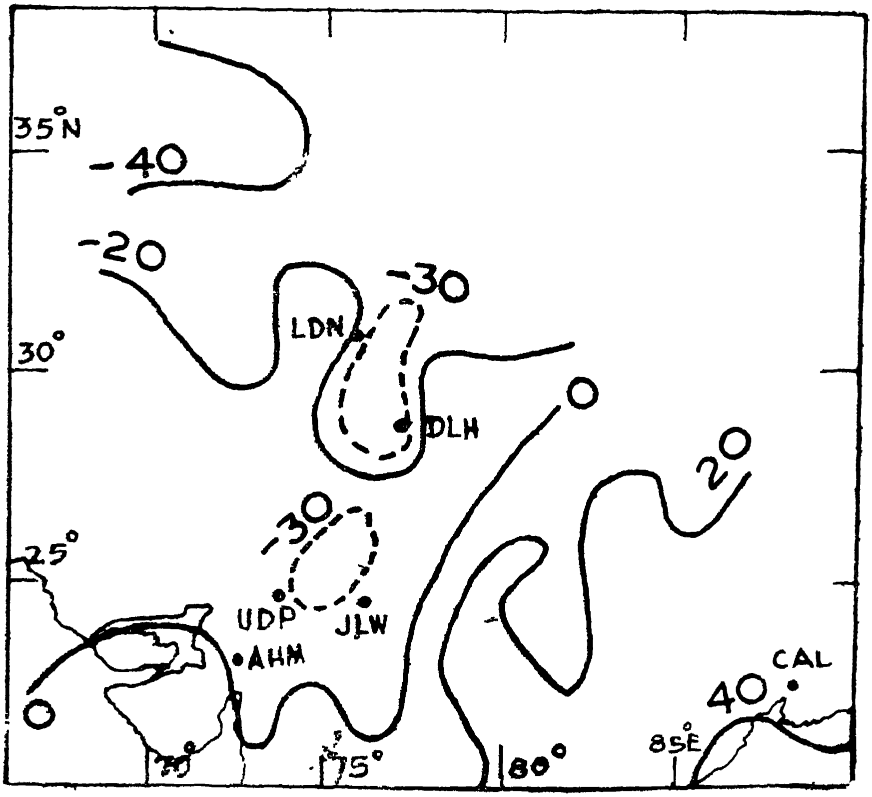


Figure 7.4 Pressure Change in 24 Hours 3 Oct., 1955

Figure 7.5 shows the upper winds and streamlines at 3000 feet (900 mb level approximately) at 09 GMT. The upper winds were plotted from the data printed in the Indian Daily Weather Report. The streamlines as drawn by the author do not represent anything more than the direction of flow. No attempt has been made to space the streamlines on the basis of the strength of the winds. However, the lines as drawn, it is believed, seever the purpose we have in view.

The data over Pakistan area may not be free from errors due to mutilations in transmission over the telecommunication channels.

The winds over the Indian region have been got checked from the scrutinised upper winds Registers available in the India Meteorological Department.

It will be noted that the centre of the depression on 3 October afternoon is near Jhalawar in East Rajasthan and that the last closed isobar of 998 mb to the north of the centre of the depression is running approximately east to west. In particular, we note that the alongated isobar running south to north as part of the depression on the morning of 4 October was completely absent on the 3 October afternoon.

Figure 7.3 shows that the pressure deficiency (12 mb) in the field of the depression is also highest near Jhalawar.

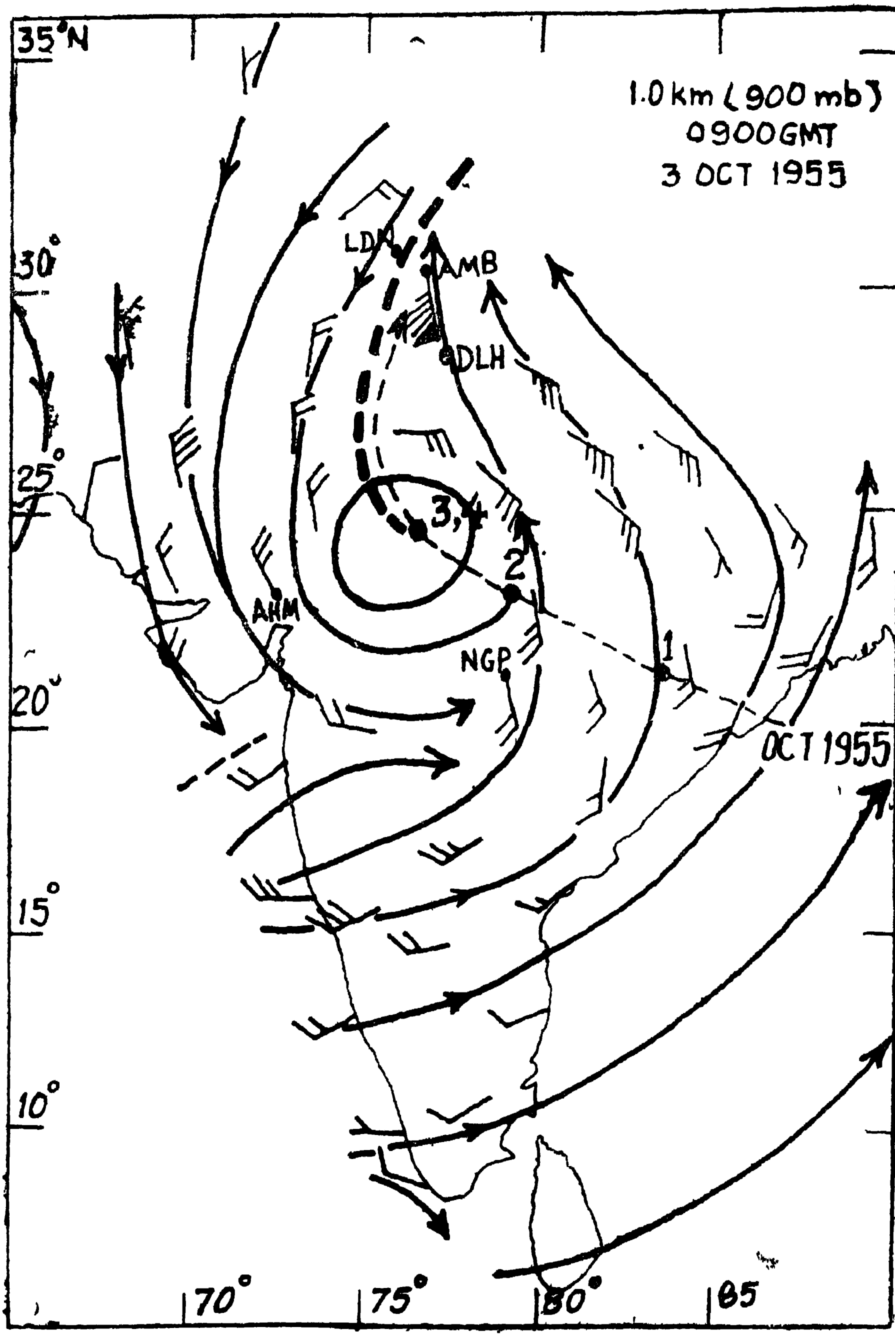

35°N
1.0 km (900 mb)
0900GMT
3 OCT 1955
30°
25°
20°
15°
10°
LDH
AMB
DLH
AHM
NGP
3,4
2
1
OCT 1955
70°
75°
80°
85

Figure 7.5

Figure 7.4 shows that there is a closed odd isopleth of minus 3 mb over Punjab (I), Haryana and neighbourhood on the afternoon of 3 October. This is an important development and we shall refer to it again in a later part of the paper.

Besides the above, there is, as is to be expected, another separate closed odd isopleth of 3 mb close to the centre of the depression over East Rajasthan.

Figure 7.5 which shows the upper winds over the entire subcontinent at the 1.0 km level, is very interesting and significant over the Haryana and Punjab (I) regions. The winds over Ambala are almost due south and of speed 85 knots while the winds to the west of 75° E are northerly 20 knots. They suggest that a trough of low pressure is developing over Haryana, Punjab (I) and Punjab (P). They also suggest that if this trough should develop further downward (we invite the reader's attention in this connection to the odd closed isopleth of 3 mb over the same region in Figure 7.4), the surface isobar would get elongated and join up with the depression over East Rajasthan. And this is exactly what happened by the morning of 4th vide Figure 7.6.

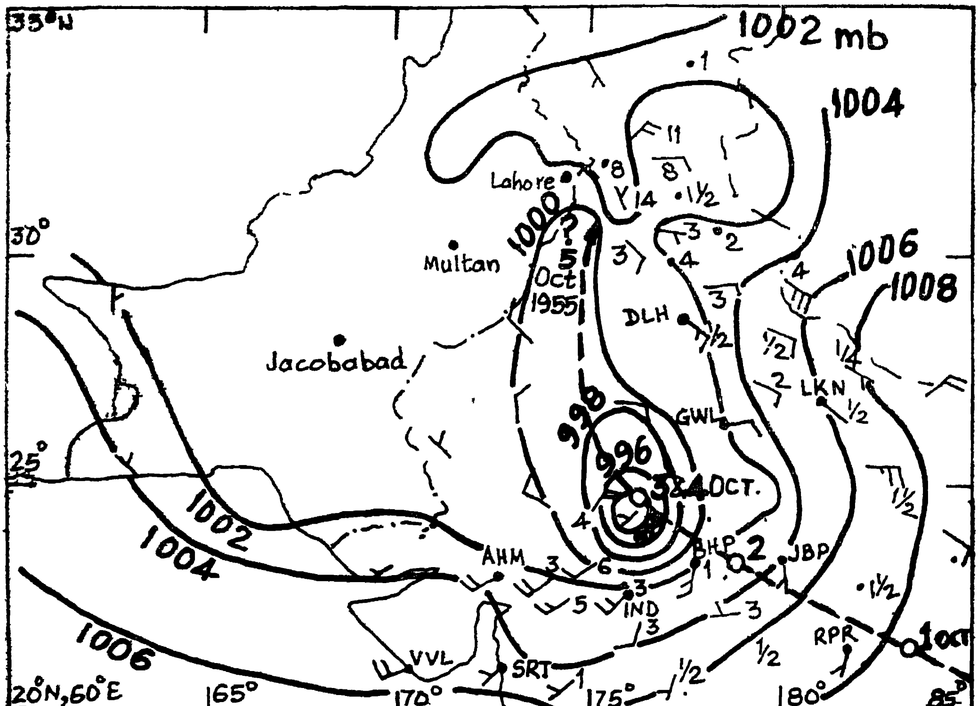


Figure 7.6 Sea Level Chart 03 GMT & Rainfall in 24 Hours Ending 03 GMT, 4 Oct., 1955

Note : Figures. 7.6 and 7.7 are based on the paper by the present author and Subba Rao (1976). The curve. 5 shown against the depression track with a question mark in Fig. 7.6 is intended merely to show the position of the low pressure area; the last remnant at sea level of the Bay of Bengal Cyclonic system. Incidentlly even this remnant disappeared by the evening of 5th.

Figure 7.7 is a composite 300 mb chart on the afternoon of 3 October. Most of the observations on this chart are for 12 GMT on 3rd at 300 mb level. However, in order to get a more complete picture of the synoptic system we have plotted on this chart, additional available observations as near to the 300 mb level as possible.

Figure 7.6 and 7.7 have been reproduced from the paper by the present author and Subba Rao (1976) through the courtsey of the Indian Institute of Tropical Meteorology, Pune.

The 300 mb chart clearly reveals the following : (a) The upper catchments of all the important Himalayan rivers are lying ahead of the axis of a 300 mb wave-trough in the westerlies. The trough appears to be diffluent (Ramaswamy, 1976) the winds ahead of the trough-axis are 40 to 45 knots while further downstream, there is confluence between the southwesterlies associated with the sub-tropical high and those associated with the wave in the westerlies. The confluence could, we believe, have resulted in a westerly jetstream over that region although we cannot conclusively eastablish this point on account of lack of actual wind observations

Consequent on the developments of these high level conditions lying superposed on the vigorous monsoon flow in the lower troposphere over Haryana, Punjab (I), Punjab (P) and the upper reaches of the rivers in the Indus system, we should expect

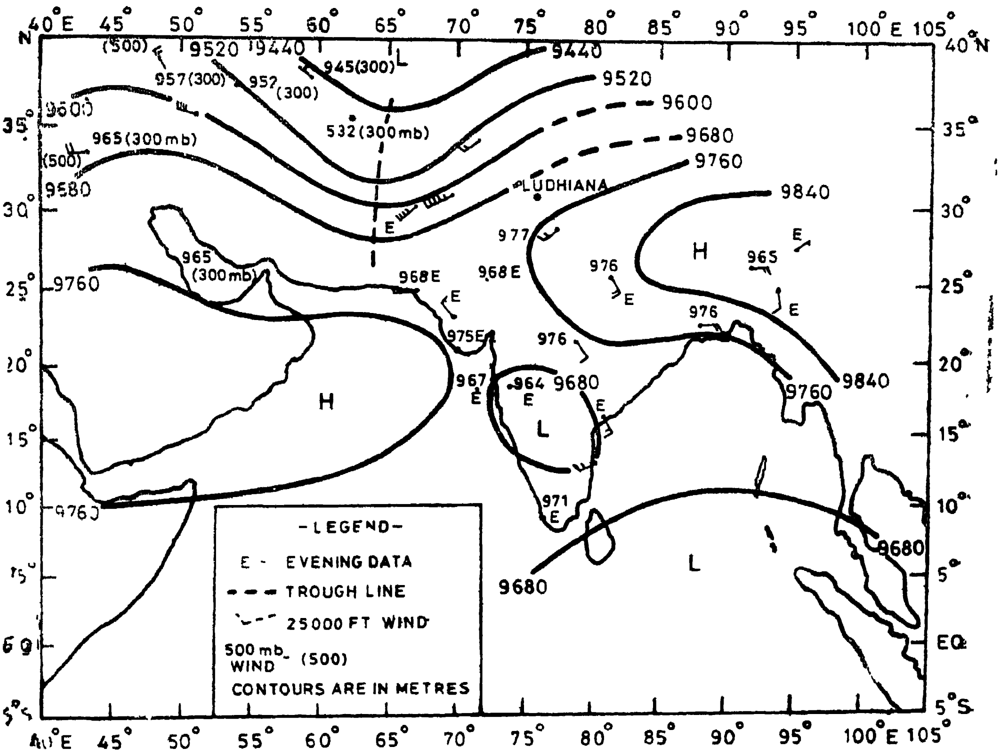


Figure 7.7 300 mb Chart (Composite), 82 GMT, Oct., 1955

very heavy rainfall during the next 24 hours over the whole of Haryana and Punjab(I) and the catchments of all the Himalayan rivers whose upper reaches possibly lay in the right entrance to a jet-maximum (Reiter, 1963).

We note at this stage another very interesting point. Even by the morning of the 4th, when the centre of the monsoon depression was still near Jhalawar, *very heavy rainfall had occurred in the plains of Haryana and Punjab (I) hundreds of kilometres away from the field of the main mosoon depression.* Ludhiana registered an all-time record of 14 inches (356 mm) by 08 GMT of 4th (see also Table 7 2 for other cases of very heavy falls of rain). In other words, *the monsoon depression at this stage, merely played the role of bringing in monsoon air into Haryana, Punjab (I) and the lower altitudes of the western Himalayas and the flood havoc was really caused by divergence in the high level wind-systems.*

On the basis of the above study, we put forward the postulate that the localised fall of pressure at sea-level of 3 mb over and near Haryana and Punjab (I) by 12 GMT on 3 October was due to the pronounced divergence at the 300 mb level in association with the wave in the westerlies. In our opinion, the fall of pressure would have resulted in the formation of a closed low* at sea level (cyclogenesis) if there had been temprature contrasts at sea-level over that area as they have in middle latitudes. If this had happened, the rainfall would have been very much heavier and the floods would have been even more disastrous.

3. Rainfall Analysis

Table 7.2 shows the occasions of 5 inches (129 mm) and over in 24 hours ending at 03 GMT on 4,5 and 6 October 1955 in the catchments of the Sutlej, the Beas, the Ravi and the Chenab.

Table 7.3 shows the noteworthy district averages of rainfall (mm) in the Punjab (including Haryana) and PEPSU in October 1955 on the dates shown. The figures have been taken from the India Weather Review, (1955) Annual Summary Part—C. Although the districts referred to, may not cover the entire catchments of the flooded rivers, the figures will give an idea of the magnitude of the flood-disaster.

4. General Conclusions

The most important conclusion reached in this study is that in September and the first half of October, before the southwest monsoon retreats from India, high-level divergence in waves in the westerlies can be the determining factor in the development of very heavy rainfall and consequent disasterous fioods in the western Himalayan rivers. The monsoon air is undoubtedly essential for the occurrence of heavy rainfall but this air can be brought into the area of heavy rainfall by a cyclonic system from the Bay of Bengal or from the Arabian Sea or by a land-depression, ever when the central region of such a system is quite

*Based on a stimulating discussion which the author of the monograph had with Professor Erik Palmen at Stockholm in 1955 about the paper by Petterssen et al (1955) (which had just then been published and its possible usefulness in the study of Indian Weather situatious).

Table 7 2 *Rainfall of 5″ (127 mm) or more in 24 Hours Innıng at 0300 HRS. I. S. S. T. over the Catchments of the Sutlej, Beas Ravi and the Chenab in Obtober 1955*

The Sutlej

District	Station	3	4	5	6
Hoshiarpur	Una	270	182	171	
Do	Garhshankar	254	129		
Do	Hoshiarpur	245	209		
Jullundur	Jullundur		177	167	
Do	Nakodar			143	
Do	Phillaur		293		
Do	Nawanshah		182		
Ludhiana	Samrala		154		
Do	Ludhiana		289		
Do	Ludhiana (Obsy)		355		
Do	Jagraon		191	292	
Ferozepur	Moga		167	335	
Do	Zıra			168	
Do	Jaimalwala			208	
Mandi	Sarkaghat			187	130
The Beas					
Kapurthala	Kapurthala		195	340	
Simla	Hamirpur		151		
Do	Dehra		183	149	
Do	Kangra		183	162	
Do	Dharmsala (Lower)	183	164		
Do	Nurpur		152	293	
Do	Dharmsala (Obsy)		197	162	
Hoshiarpur	Dasuya	161	226		
Do	Tanda		127	127	
Amrıtsar	Raya		183	367	
Do	Patti		150	187	
Gurdaspur	Batala		215	475	
Do	Tibri		173	259	
Do	Pathankot		134	211	139
Do	Malıkpur				127
The Ravi					
Kathua	Kathua			216	
Do	Basbhli	152	228	228	
Gurdaspur	Gurdaspur		252	370	
Do	Dalhousie (O bsy)	371	274	287	
Do	Madhopur		143	351	

Table 7 2 (*Contd.*)

District	Station	3	4	5	6
Chamba	Chamba	134	157	127	
Do	Ludreva		128		
Do	Chatrari		140	146	
Do	Batheri	234	284		
Do	Kalatop		193	165	
Do	Tissa		135	156	
	The Chenab				
Jammu	Jammu			160	
Udampur	Ramban		127		
Simla	Koksar (Obsy)			167	
Do	Condla	143	159	147	

Table 7.3

	District Averages (mm)			
District	3	4	5	6
Ambala		71	71	56
Simla		33	43	
Kangra	58	130	127	53
Hoshiarpur	30	210	175	91
Jullundur	28	190	132	
Ludhiana	25	210	157	
Ferozepur		71	84	
Amritsar		165	226	28
Gurdaspur		185	320	94

far away from the area where heavy rainfall occurs. In other words, the cyclonic vorticity and lower-tropospheric convergence associated with the cyclonic system from the Bay of Bengal or Arabian Sea or by a land-depression may not necessarily play a role in the development of the heavy rainfall; these cyclonic systems

Note. A case somewhat similar to the present one occured in September 1962. It had been studied by Venkataraman and Rao (1965). They have stated in their paper that the "flooding was more due to the breaches in the numerous rivulate and canals that due to overflowing of the major rivers". This statement is, I regret to say, not correct. According to the Monthly Weather Report for September 1962 and India Weather Review Annual Summary Part—C for 1962 published by the India Meteorological Department, severe floods had occurred in the major rivers in the Indus system in September 1962.

may only provide the agency to bring in the monsoon air into the area where heavy rainfall subsequently occurs.

The heavy rainfall can be forecast well-in-advance, provided the synoptician receives adequate amount of upper data from Pakistan, Afghanistan and Iran sufficiently early. Until our requirements in this respect are fulfilled, the forecaster can indicate in his bulletins, the possibility of heavy rainfall as soon as he is able to infer from other available evidence that the monsoon depression would recurve to the north towards the western Himalayas.

The above conclusion should not be taken to imply that the recurving cyclonic system by itself cannot, at a later stage, cause a secondary spell of heavy rainfall associated with lower tropospheric cyclonic vorticity and convergence. Such a possibility has also to be kept in mind by the weather forecaster.

5. Flood Damage

The following is an account of the damage caused by the floods, as published by the India Meteorological Department in the India Weather Review, 1955, Annual Summary Part—C.

"Due to the torrential rains, Punjab and PEPSU states came under the grip of severe floods which, according to press reports, were the most disastrous in recent history. Thousands of villages were reported to have been isolated from the rest of the country and food supplies had to be air-dropped by the Indian Air Force personnel at many places. Hundreds of houses collapsed in the cities and towns of the Punjab (I) and a large number of people were reported to have been killed or seriously injured. The waters of river Jamuna near Delhi rose to a dangerous level and thousands of people residing on its banks in the neighbourhood of Delhi had to seek shelter inside the city. On 8th October, the city of Delhi itself was threatened by the rising waters of Jamuna, which according to press report reached a record level on the 9th morning and then subsided. According to a statement issued by the Chief Minister of Punjab, 7000 out of the State's 75,000 villages were inundated, 75,000 houses destroyed and cash crops worth 35 crores of rupees damaged by the floods. The total death roll on account of the floods and house collapses was estimated to be about 1500 according to newspaper reports.

CASE No. 8

CATASTROPHIC FLOODS IN THE RIVERS IN SOUTH KERALA IN AUGUST 1958

1. Introduction

A very good and exhaustive paper on the above subject on the basic synoptic, hydrological and hydrometeorological aspects has been published by George, Raman and Raghavan (1966). Since they have utilised in their analysis, all high level wind and temperature data available in 1958, the author of this monograph has little to add to what the above-mentioned authors have already brought out in their paper. However, as their contribution is an important one, our monograph will be very incomplete if we do not include in it, at least a summary of their paper with a few comments here and there.

The authors have referred to the floods as Catastrophic. In comparison with the other cases of catastrophic floods discussed in this monograph, it is difficult for the writer to state whether the South Kerala floods should have been referred to by George et al as Catastrophic or it would have been sufficient if they had categorised them as Severe. However, we would prefer not to differ from them in this matter as we are here mainly summarising their work.

2. Hydrological Data

The floods were in the nature of "Flash Floods", they occurred on 7th August 1958 and the rivers chiefly affected by them were the Moovatupuzha, Meenachil Manimala and Pamba, the worst affected among them being Manimala. A map showing the physical features of the region may be seen in Figure 8.1. Details of the flood-level reached in these rivers are given in Table 8.1. The maximum discharges occurred in these rivers on 8 August 1958 and their values may be seen in Table 8.2.

3. Synoptic Situation

The lower, middle and upper tropospheric processes associated with the heavy rainfall are summarised below :—

3.1. Orographic Effect

The upper winds upto about 5000 feet a.s.l. were more or less northwesterly over the Kerala Coast. This was not a favourable situation for the monsoon current to be lifted orographically over the Ghats.

3.2 Lower tropospheric developments

The authors have shown that small-scale vortices developed at levels close to the surface. They have referred to these low-level developments as Micro-vortices. As

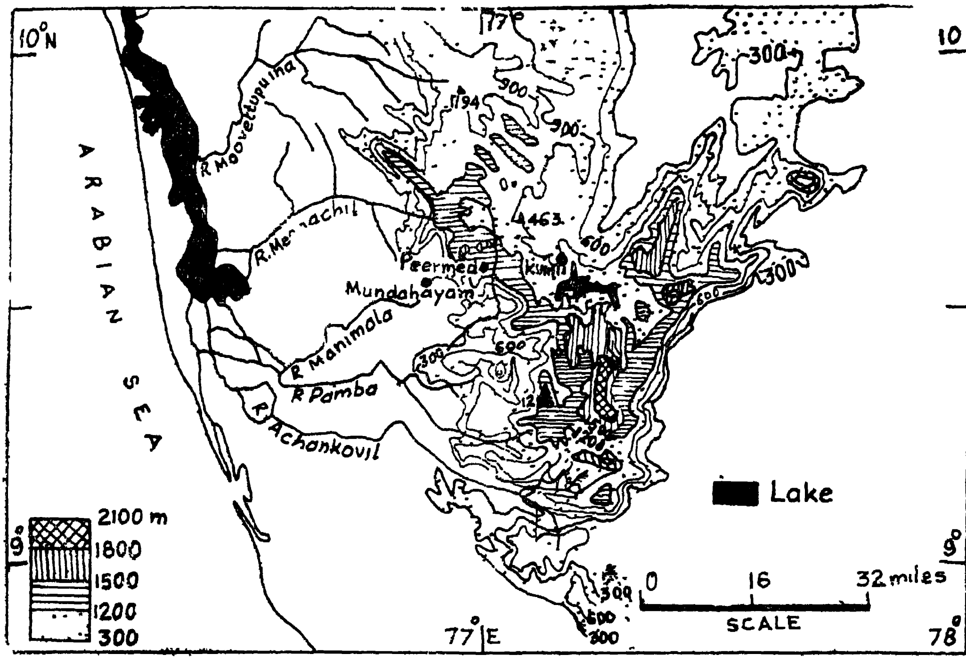


Figure 8 1

Table 8.1 *Details of flood levels in the various bridges recently constructed in Meenachil, Manimala and Pamba (the levels noted are not with reference to m.s l.)*

1. Meenachil river

Bridge at Erattupetta above the confluence of Poonjar and Meenachil

	(ft)
Bed level of river	74.0
Deck level	100.6
M.F.L. reached during the present floods	109.5
Previous M.F.L.	100.0

2. Manimala river

(i) Bridge at Koratty-upstream of Manimala near Brumali

Bed level	70 0
M.F.L. during the present floods	100 0 (7th morning)
Previous M.F.L.	95.5

Water very nearly touched the bottom of girders at central span

(ii) Manimala Bridge

Bed level	74.0

Table 8.1 (*Contd.*)

Top of piers	104.5
Flood level during Aug. 1958	116.0
The present flood reached 12 ft above 1099 flood level. At Thondara Bridge site, the flood waters reached about 1099 floodlevel.	
3. Pamba river	
Bridge at Ranni (under construction) M.F L. reached during the present floods	
oame as previous M F.L.	62.0 ft
The flood waters overflowed the right bank for a depth of 12 ft.	
The rise of water at this site was sudden. It rose to 22 ft in 2 hours and 27 ft. in 4 hours.	

Table 8.2 *Maximum discharge on 8 Aug 1958*

River	Maximum discharge (cusec)
Pamba	45000
Manimala	23800
Meenachil	18260
Achencoil	10200
Moovattupuzha	25000
Total	122260

the horizontal extent of these vortices would have covered* the region between contiguous observatories maintained by the India Meteorological Department along the West coast or would have extended "at least well-beyond the range of observations from a single point", the writer would prefer to use the term "meso-scale vortices" or simply as meso-vortices instead of "micro-vortices". Figure 8.2 shows the development and movement of such meso-vortices between 5th and 7th August. Very heavy rainfall occurred between the 5th and 6th and again between the 6th and 7th. These have been, according to George *et al*, at least partly due to the meso-vortex. For instance, the south-wards shift of the vortex corresponded to a southward shift of the area of heavy rainfall towards Peeramed. The 24-hours pressure changes at the various stations support their view. By the 8th, the meso-vortex disappeared, the normal features of the isobaric configuration were restored and the rainfall decreased considerably.

*The criteria stated above reasonably fulfill the definition of Meso-meteorology and Micro-meteorology as given in the Glossary of Meteorology (1960) pnblished by the American Meteorological Society.

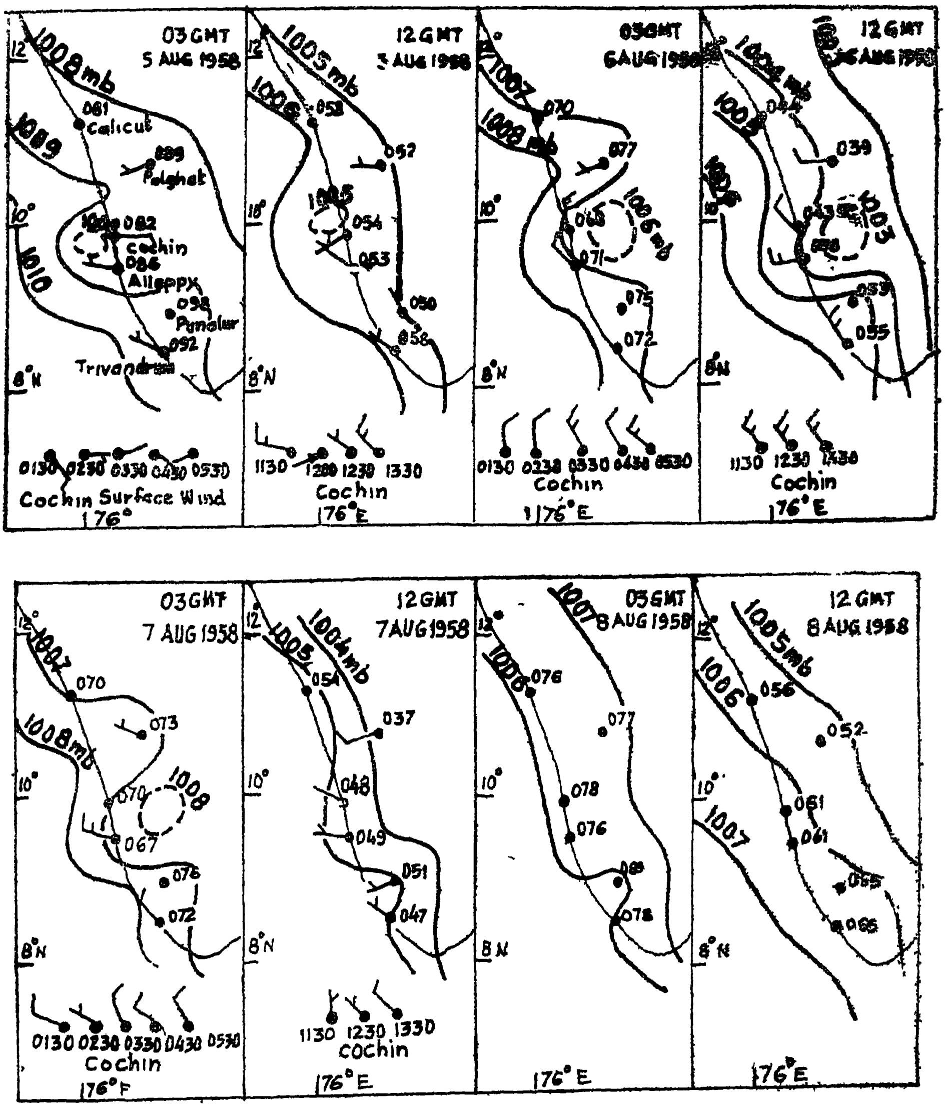


Figure 8.2 Meso-Vortices Kerala Cost

3.3 Mid-tropospheric development

Figure 8.3 shows the vertical time-section of Trivandrum (08°29′ N 76° 57′E) on 6 and 7 August 1958. The wind-discontinuity between the Westerlies and the Easterlies between 3 & 6 km may be noted. The discontinuity became more marked and a feeble perturbation which appeared over the discontinuity, developed into cyclonic vortex right over the high ranges adjoining Kerala as was evident from the upper wind observations of Trivandrum and Triuchirapally (10°49′N, 78°42′E) between 3.0 and

Table 8.3 *Depth-area values for standard areas for 24 hrs*

Area (Sq. miles)	Average depth (inches) Actual	Calculated
100	12 6	12 6
500	11.4	11 2
1000	10.1	10.1
1500	9 0	9.2
2000	8.1	8 4
2500	7 3	7.7
3000	6.8	7 2
5000	5 5	5 5
8000	4.0	3 9
10000	—	3.1

6 km. The vertical time section of Trivandrum (Figure 8.3) shows that the cyclonic vortex passed over Trivandrum on the night of 6-7 August and that the winds between 700 and 400 mb levels were within the field of cyclonic circulation of the vortex.

3.4 Upper tropospheric developments

The authors have produced in their paper, a vertical time-section of Madras between 1 and 8 August 1958 (diagram not reproduced here). This time-section indicates that the easterly jet stream over Madras was in its accelerating stage during the period 2 to 5 August and in its decelerating stage on 6 & 7 August. The authors point out that the exceptionally heavy downpour over South Kerala occurred on the 6th afternoon and night.

3,5 Vertical Velocities

The authors have conputed the vertical velocities associated with the heavy rainfall. The vertical velocity of 3.5 cm/sec computed by them agrees fairly well with values calculated from divergence calculations using winds for 3 stations in a triangle over this area. According to George et al, their figures are also of the correct order of magnitude compared with the average vertical velocity off 4 cm/sec computed by Palmen (1957) from a study of the Hurricance Hazel.

4. Rainfal Analysis

The catchment of the four rivers Moovatupuzha, Meenachil, Manimala and Pamba which were affected by the floods covered a total area of about 1000 sq. miles. This area contained a network of 30 raingauge stations.

It is seen from the rainfall records of these stations that the heaviest rainfall occurred over and near Peermed town. *Nearly 14 inches (34 cm) of rain occurred in*

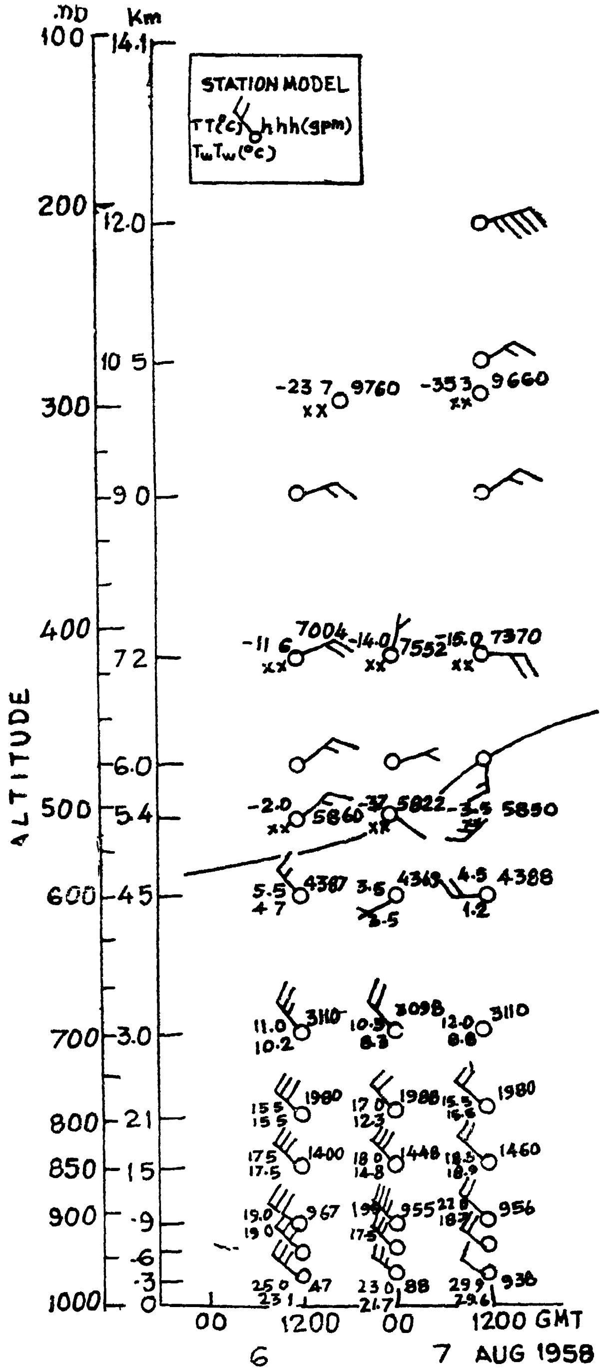


Figure 8 3 Vertical Time-Section of Trivandrum

about 16 hours over and near Peeramed on the day of the flood. The intensity of the rainfall can be judged from the fact that Peeramed gets an average rainfall of 201 inches in a whole year.

5. Isohyetal Analysis and Depth-area Distribution of storm Rainfall

Figure 8.4 shows the isohyetal map for 24 hours ending at 0830 hours I.S.T. of 7 August 1958. Table 8.3 shows the depth-area values for standard areas corresponding to this isohyetal map. The depth-area distribution for this rainfall situation gave an average of 10.3 inches over 1000 sq. miles during 16 hrs. on the day ending at 0830 IST on 7 August 1958. This works out to an average rate of rainfall of 0.6 in/hr over the catchment. This nearly agrees with the value arrived at theoretically from moisture considerations only, considering the uncertainties about actual duration of rain.

6. General Conclusions

The following is a verbatim quotation from the paper by George et al :

"The study has revealed that although orography plays no small role in lifting the monsoon current and causing heavy rainfall and consequent floods in Kerala, there are several other important mechanisms which cause intense falls. It was the combination of all these factors at the various levels extending right from the surface up to the upper troposphere which was responsible for the heavy rainfall of exceptional intensity over south Kerala on 6 to 7 August 1958. Since there was rain over this region during the preceding days also, the ground was fully saturated when the heavy precipitation occurred. This facilitated the entire rainfall to flow down the rivers as run-off............From theoretical and physical considerations of moisture content of air layers, the intensity of point rainfall at the centre and of average rainfall over an area of 1000 sq. miles have been calculated which are found to agree very well with observed values".

7. Special Comments by the Author of the Monograph

The attention of the reader is invited to our studies of severe floods over Kerala and the upper catchments of the Cauvery prior to 1932 for which we had no Radiosonde or high level wind-data. The paper by the author and his collaborator Kailasanathan (1976) is also relevant in this connection. In these contributions, we have pointed out that undue importance had been given in the past to the orographic effect of the Western Ghats.

8. Flood Damage

The authors have not given in their paper any detailed account of the flood-damage. However, in the beginning of their paper, they have stated that the floods resulted "in heavy loss of human lives and live-stock also of property worth many lakhs of rupees."

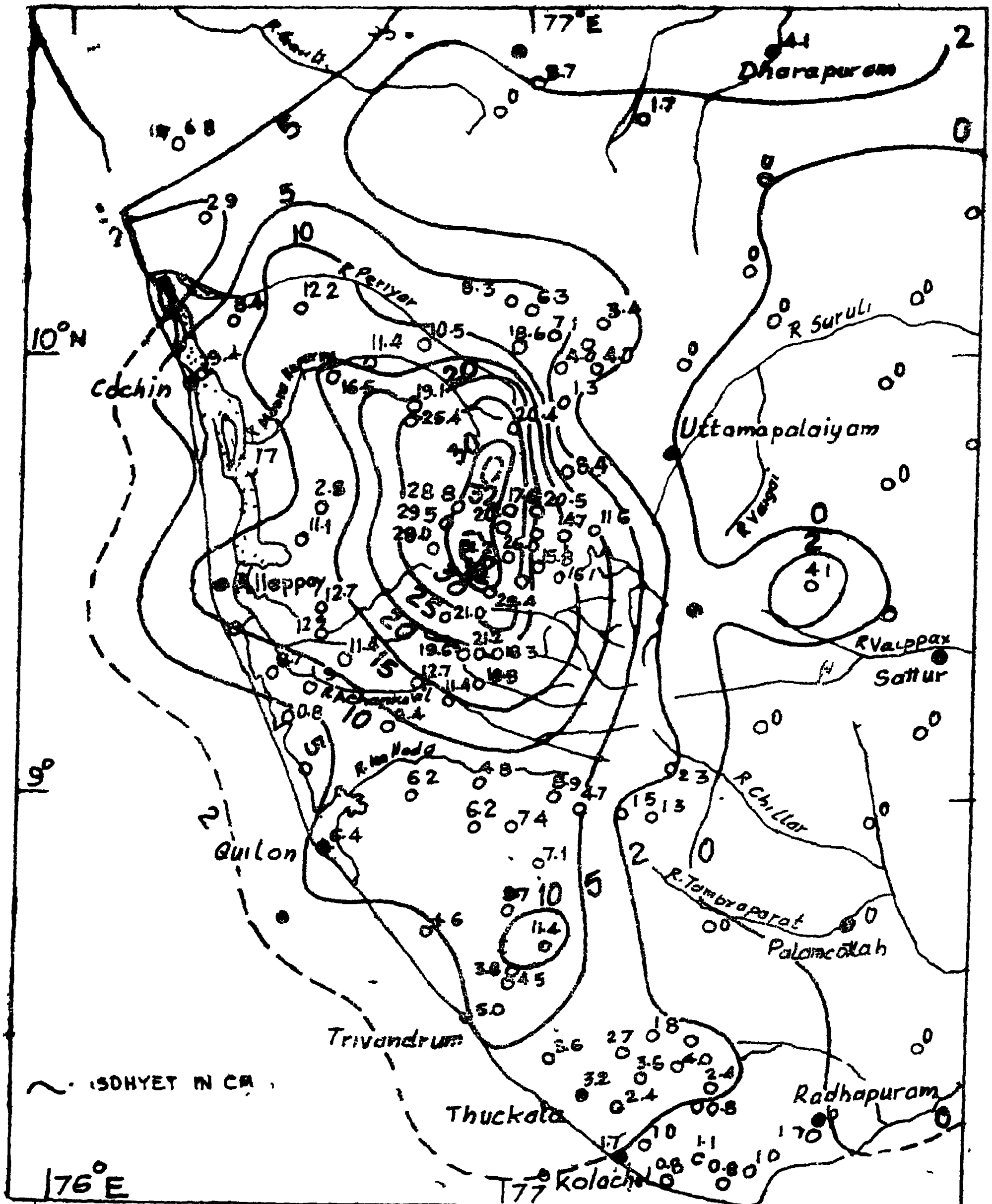


Figure 8.4 Isohyetal Map for 24 Hours Ending at 0830 Ist of August, 1958

CASE No. 9

CATASTROPHIC FLOODS IN THE TAPI IN SEPTEMBER 1959

1. Hydrological data Relating to the Flood

According to Parmer and Shelat (1970), Purohit (1970) and Rao B. S. (1970), the floods in the Tapi in September 1959, are next only to those in August 1968 in regard to the highest gauge level as well as peak-discharge recorded near Surat. However, the data relating to the September 1959 floods do not find a place in the UNESCO catalogue of Very Large Floods (1976). This is presumably because the catalogue contains a list of only 5 cases of Very Large Floods in each river and consequently inclusion of the present one would have increased the number to six floods in the case of the Tapi. This is supported by the fact that the floods on the same occasion in the Narmada have been included in the catalogue as it falls within the number of 5 floods for that river.

In view of the above, the required hydrological data relating to the Tapi in respect of the September 1959 floods have been extracted to the extent that was possible, from the papers presented by the authors mentioned in paragraph 1 above. The figures are given in Table 9.1.

Table 9.1 *Hydrological data relating to the floods in the Tapi in September, 1959.*

Gauging station	Q_s max M/s.	Date	Highest gauge level recorded during the floods in mm.	Total duration of the floods in (hours)	Remarks.
Ukai (110 km from the town of Surat)	37300	17.9 59	31.2	120	

2. Large-scale Synoptic Situations

The main synoptic situation which was responsible for the catastrophic floods, developed between 7th and 14th September 1959. It is, however, important to mention that even during the first week of September 1959, there was an extended low pressure area over Madhya Pradesh and the adjoinning areas which had caused moderate rainfall over the Tapi catchment with one or two heavy falls in the lower reaches of that river. Kamrej and Mandvi in the Surat district had reported rainfall of 82 mm. and 80 mm. respectively on 1st September. In addition, Multai in Betul District had reported 76 mm. of rain on 6th September.

According to the India Weather Review of the India Meteorological Department, the seasonal trough of low pressure over north Orissa, the Bihar plateau and the adjoining areas in Gangetic West Bengal and Madhya Pradesh had become more

marked by the morning of 7th September under the influence of a low pressure wave from the east. The well-marked trough persisted with the same intensity for the next 2 days. On 9th morning, a fresh low pressure-wave was moving westwards across North Bay. In association with it, a land-depression formed over North Orissa and the adjoining parts of Gangetic West Bengal and Bihar plateau with its centre at 0830 hours IST on 10th about 150 Km east of Jharsguda. The associated upper air-cyclonic circulation extended upto 6 Km. asl. The track of the cyclonic system from 12th September onwards may be seen in Figure 9.1.

The most interesting feature in the track is that it had a significant westsouth-westerly component in the movement until it crossed the longitude of 80°E. It moved very slowly upto 13th and reached its maximum intensity on 14th September when it was centred near Nagpur. The pressure deficiency at the centre of the depression at this stage was a little more than 10 mb. As is characteristic of September depressions, it caused exceptionally vigorous monsoon over a restricted area. After 14th, it began to move northwestwards and weaken. It merged with the seasonal low over Pakistan by the morning of 16th.

3. Why did the second Low Pressure system have a Southerly Component between the 10th and 14th September ?

An examination of the available data clearly shows that heavy rainfall would not have occurred over the catchment of the Tapi in such large amount if the depression had moved westnorthwestwards or northwestwards in the usual way. It is therefore essential to know why the depression had acquired a southerly component in its movement between 10th and 14th September. Figure 9.2 shows the area of 24 hours pressure changes between 03 GMT of 11th and 03 GMT of 12th September 1959. The positions of the centre of the depression at 08 hours of 12th and 13th have also been shown on the same diagram. The largepressure rises all round, and the narrow corridor of negative pressure changes extending from NE to SW and its association with the observed track may be noted.

Figure 9.3 shows a composite upper wind flow pattern at 00/12 GMT at 9.0 Km level which lay above the field of the depression. The flow pattern at this level may therefore be considered to have contributed to the steering of the depression.

4. Rainfall Analysis

Table 9.2 shows occasions of rainfall exceeding 75 mm. or more in 24 hours over the catchment of the Tapi associated with this case of floods. The districts have been so listed in the Table that those with increasing longitudes appear progressibely lower down in the Table.

An examination of the Table clearly shows that heavy rainfall of 75 mm or more occurred only on 13th, 14th and 15th (apart from that on 1st and 6th September) and that heavy rainfall did not extend to the west of langitude 75° E. The town of Surat which was over-whelmed by the floods did not experience any heavy rainfall at all.

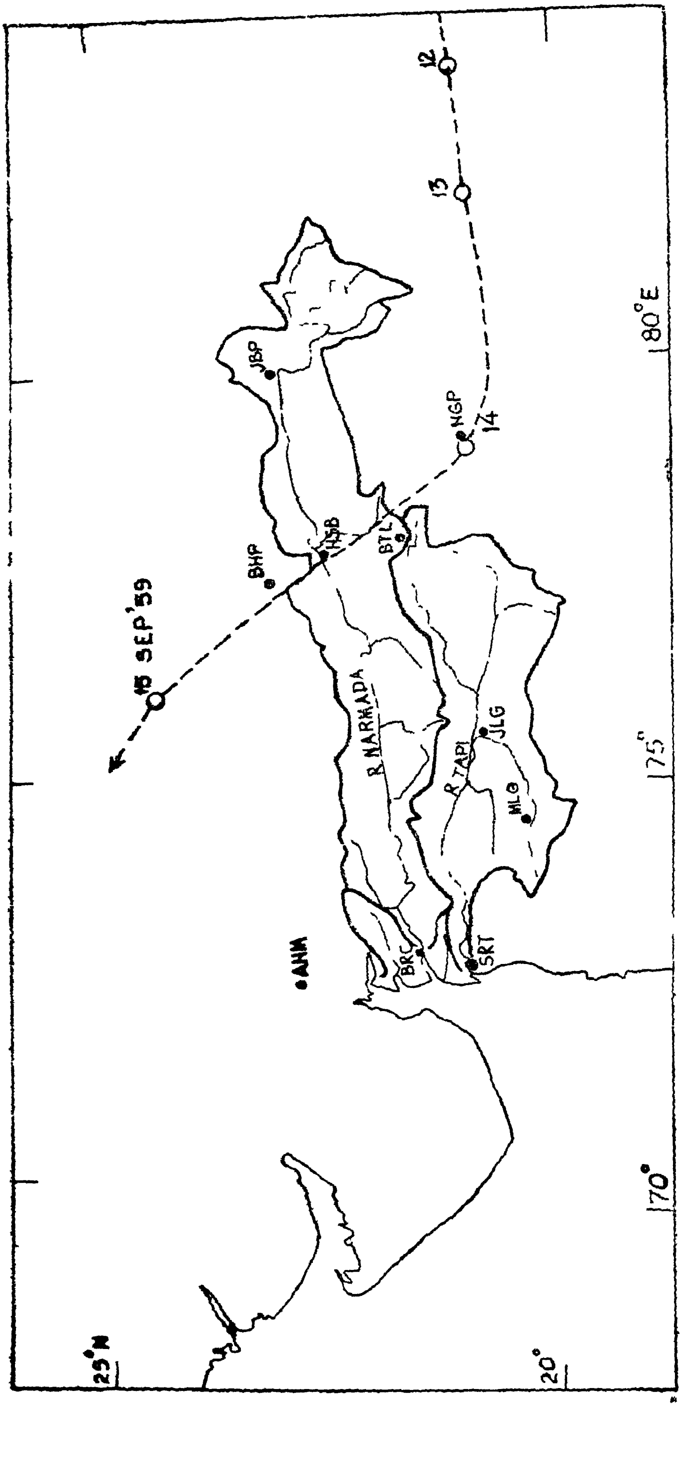


Figure 9.1 Tapi & Narmada Basins

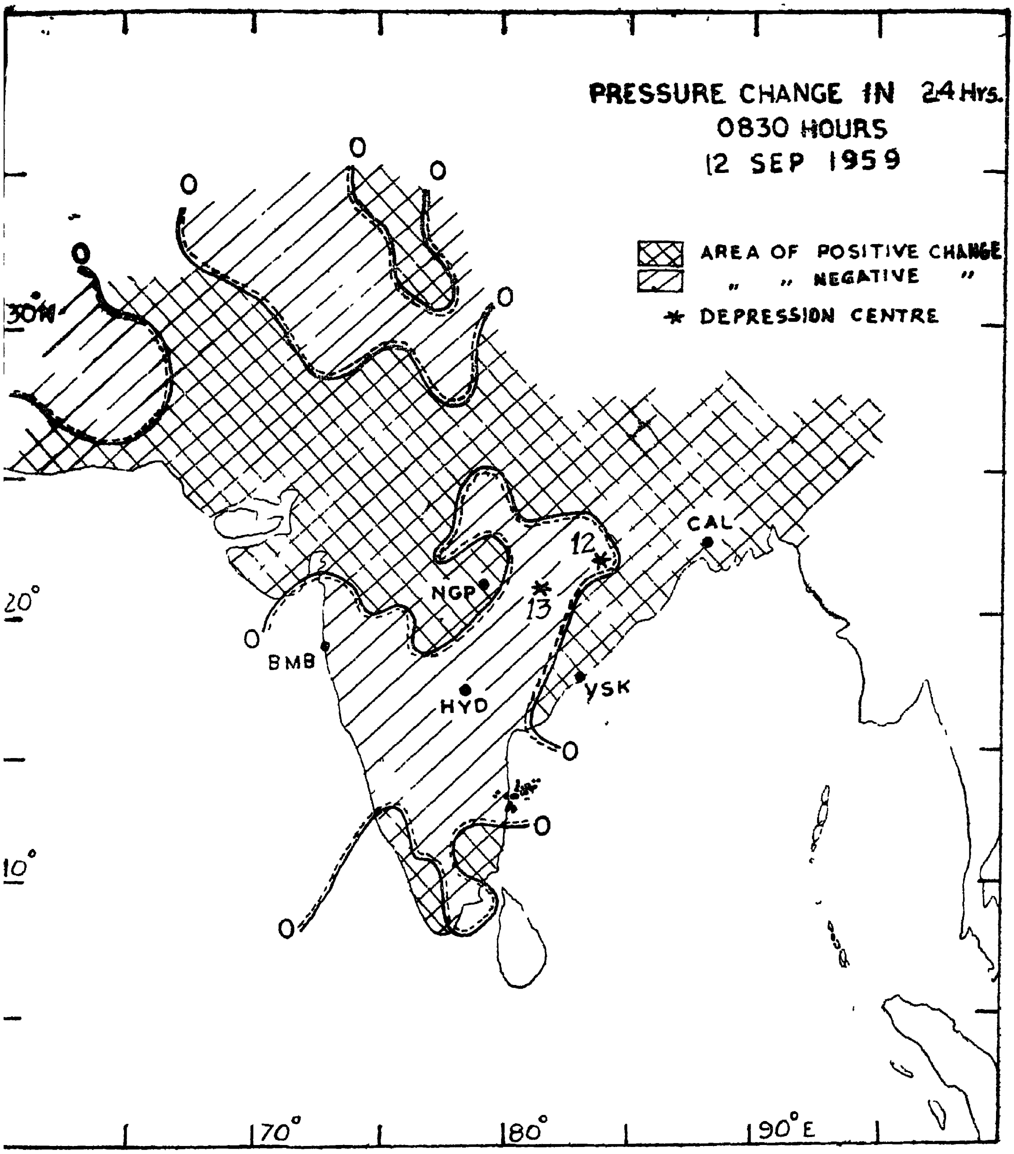

PRESSURE CHANGE IN 24 Hrs.
0830 HOURS
12 SEP 1959
AREA OF POSITIVE CHANGE
" " NEGATIVE "
DEPRESSION CENTRE
30°N
20°
10°
170°
180°
190°E
CAL
NGP
BMB
HYD
VSK
12
13
0

Figure 9.2

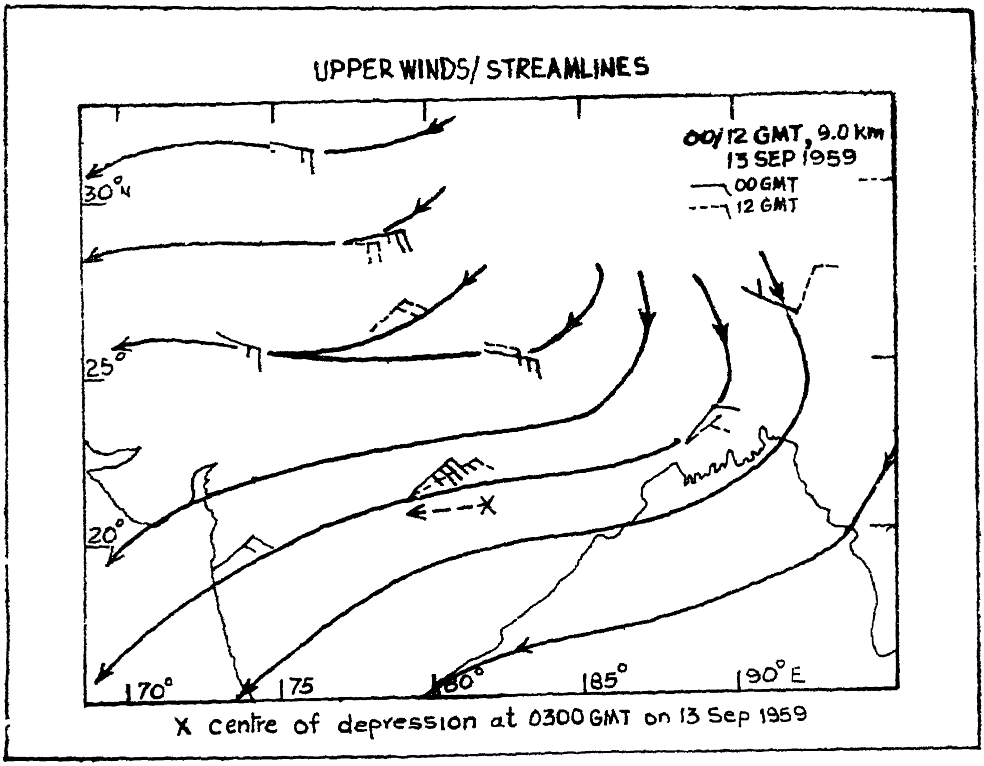


Figure 9.3

According to Pant et. al (1970) the daily average of rainfall over the catchment of Tapi as a whole was 73 mm. on 14th September and 77 mm. on 15th. They, had, however, not presented any isohyetal analysis in their paper.

5. Isohyetal Analysis

The isohyetal pattern of the rainfall over the Tapi Catchment in the maximum 2-day storm-period 14th-15th September have been drawn by us. It may be seen in Figure 9.4. It will be seen that :

a) The maximum 2-day rainstorm centre lay near Tepara to the northnorth west of the well-known district town of Akola;

b) The 100 mm. isohyet extended slightly to the west of Jalgaon and thereafter extended northwestward upto 74°E;

c) *Heavy rainfall did not extend westwards upto Surat;*

d) *The contribution to the floods was almost entirely from the rainstorm in the upper reaches of the river.*

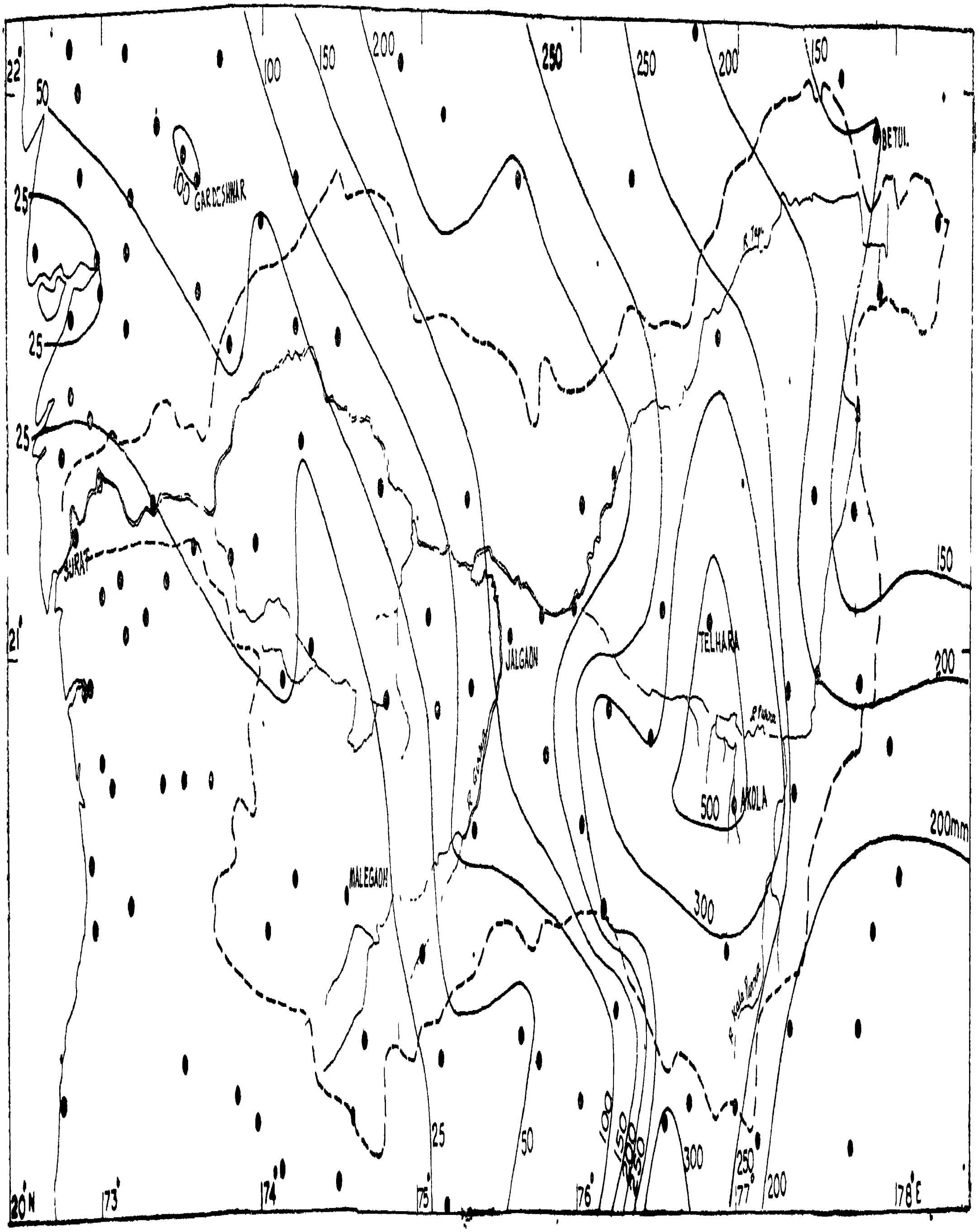

22°
21°
20° N
73°
74°
75°
76°
77°
78° E
GARDESHWAR
BETUL
SURAT
JALGAON
TELHARA
AKOLA
MALEGAON
R. Tapi
R. Purna
R. Girna
R. Kata Purna
25
50
100
150
200
250
300
500
200mm

Figure 9.4

Table : 9.2 *Rainfall Exceeding 75 mm or More over the Catchment of the Tapi Between Ist and 17th September 1959*

Sl.	Raingauge Stations.	DATES 13	14	15	Sl. No.	Raingauge Stations.	DATES. 13	14	15
I·	*Jalgaon Dt.*					*Akola Dt.*			
1.	Jolgaon	—	—	130	21.	Telhara	—	392	214
2.	Pachora	—	—	82	22.	Patur	—	168	128
3.	Erandol	—	—	112	23.	Sirpur	—	201	—
4.	Chopda	—	—	126	24.	Murtajapur	—	89	153
5.	Janner	—	—	120	VI.	*Amraoti Dt.*			
6.	Bhusaval	—	—	108	25.	Amraoti	—	104	78
7.	Edalabad	—	77	94	26.	Badnera	114	124	—
8.	Yaval	—	104	—	27.	Kholapur	—	142	—
9.	Rover	—	—	115	28.	Achalpur	—	131	—
II.	*Buldana Dt.*				29.	Daryapur	—	152	75
10.	Buldana	—	125	128	30.	Anjangaon	107	—	—
11.	Malkapur	—	122	227	31.	Chichalda	105	118	—
12.	Nandura	—	165	130	32.	Dharni	—	130	125
13.	Jalgaon	—	137	131	V.	*Betul Dr.*			
14.	Khamgaon	147	137	—	33.	Multai	—	85	
15.	Shegaon	—	288	225					
16.	Dhamangaon	—	86	128					
17.	Hiwarkhed	—	=	76					
III.	*Akola Dt.*								
18.	Akola	—	185	365					
19.	Balapur	305	102	—					
20.	Akot	145	82	—					

Kamreej and Mondvi (Surat Dt) : 82 mm & 80 mm. respectively on Ist Sept. and Multai (Betul Dt) : 76 mm on 6th.

6. Time lag between Floods in the upper Reaches of the River and Floods in the town of Surat

It is obvious from the above that the catastrophic floods which occurred near Surat was the result of the flood waters from the upper reaches of the river flowing downstream to Surat. It is seen from the papers of Rao (1970) and others mentioned earlier that there will be time-lag between floods as recorded at gauge-site in the upper reaches and the rise of the gauge level at Surat.

The time-lag of 2 days observed by us in the present case, is reasonable consistent with the mean figures given by Rao, B. S., (1970) for high floods to reach Surat. His figures are reproduced in Table 9.3.

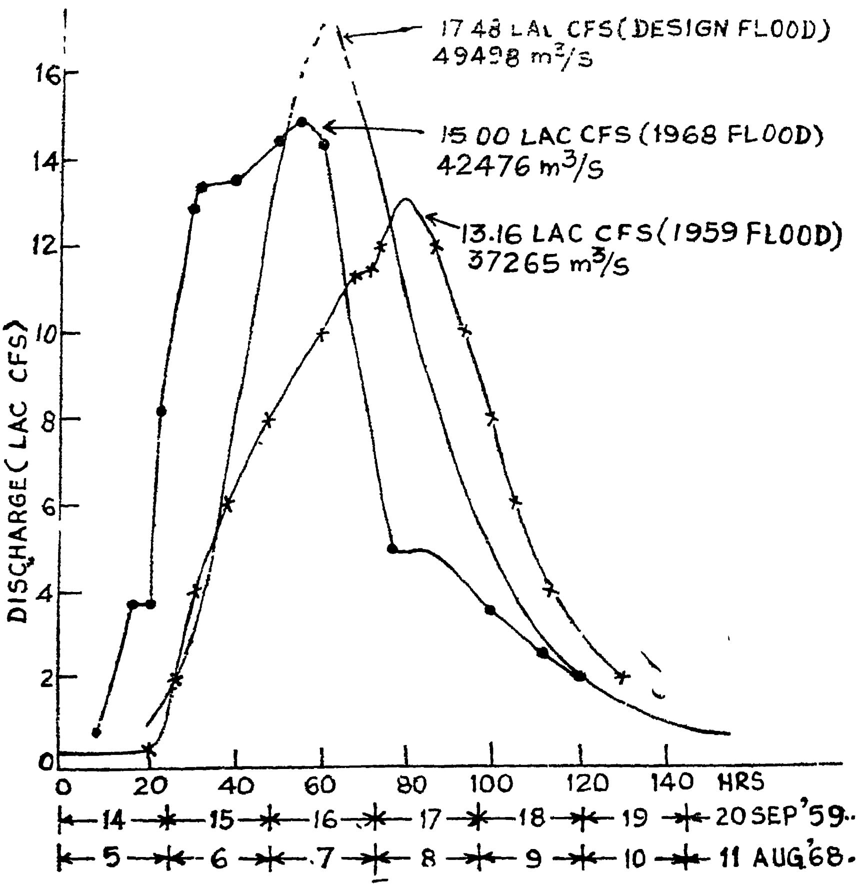


Figure 9.5

7. General Conclusions

The September 1959 floods is a good instance of disastrous floods at Surat as a result of heavy floods in the upper reaches of the river. It would appear from the figures given by Rao, B. S. (1970) that a *prior warning of more than 24 hours would be possible for floods of the type at Surat solely on the basis of the gauge height readings.*

The discharge hydrograph at Ukai shows that the rate of increase of flood-discharge in September 1959 floods was less than in the catastrophic floods in August 1968. The peak value was also less by about 5200 m^3/s. It is also clear that the floods at Surat would have been less severe, if the monsoon

Table 9.3 (*Based upon estimates by Rao (1970)*)

S. No.	Name of the Gauge site	Distance from Surat in Kms.	Time-lag from Gauge-site to Hope-Bridge at Surat for high floods (Hours)
1.	Bhurhanpur (Maharashtra)	463	29
2.	Bhusavel* (Maharashtra)	400	25
3.	Nanded (Maharashtra)	312	19
4.	Sindkeda	285	18
5.	Ukai Dam-site	110	7
6.	Kathore Bridge-site	26	2

*The Observatory at Bhusaval recorded its heaviest fall at 03 GMT of 15th September. The floods reached its peak value at Ukai near Surat on 17.9.59.

depression did not have a southerly component in its movement. Hence the forecasting of the southerly component in the movement of the depression wellahead in similar cases in future, is a "must" for the synoptic meteorologist, as it would be helpful in issuing even more timely warnings against the floods than purely from the gauge height readings at different points of the river upstream.

8. Flood Damage

The following is an extract from the account of damages caused by the catastrophic floods, in the Tapi in September 1959 as given by Palel N. K. (1970)

Extent of area of damage	Damage caused
(i) About 300 sq. miles covering about 182 to 196 villages over and about Surat City.	(i) Urban; standing crops were damaged in villages Bhatpore, Kosad, Adajan, Ved, Mota Varacha, Katargam Pal, Bhatha etc.
(ii) Standing crops affected in 51,839 acres.	(ii) Breaches in the Rly. line at Kosad and Udhna on western Rly. in 3,000' length between Surat and Udhna and 280' near Kosamba, Surat City Power Supply was cut off for 48 hours.
(iii) Kharland offected 227 acres of Chorasi Olpad. Damage to Agricultural 21,615 acres Kamraj and Mandvi Taluka.	(iii) City wall near Variavi gate collapsed in a length of 200'.

Flood-damage continued :

Surat

(i) Areas of Nanpura, Haripura, Machhliwad, Kashiward, Dhastipura, Railway Station area, Navsari Bazar with 3′ to 15′ depth of water.

(ii) ½″ water works was also under water.

(iii) All the traffic over Makai bridge connecting the Eastern and Western parts of Surat town was suspended from 16.9.59

(iv) Sardar Patel Museum was under 8′ of water.

(iv) 150′ length of Dutch garden wall damaged.

(v) Parapet wall in 150′ length on Makai bridge was damaged.

(vi) Invaluable and rare exhibits, paintings and show pieces in the Sardar Patel Museum were totally lost.

(vii) Newsprint worth Rs. 70,000/- carried away in flood from the office of the 'Gujarat Mitra Press'.

(viii) Deep ditches and cuts were formed at places exposing power cables and damaging drainage system (under ground)

(ix)

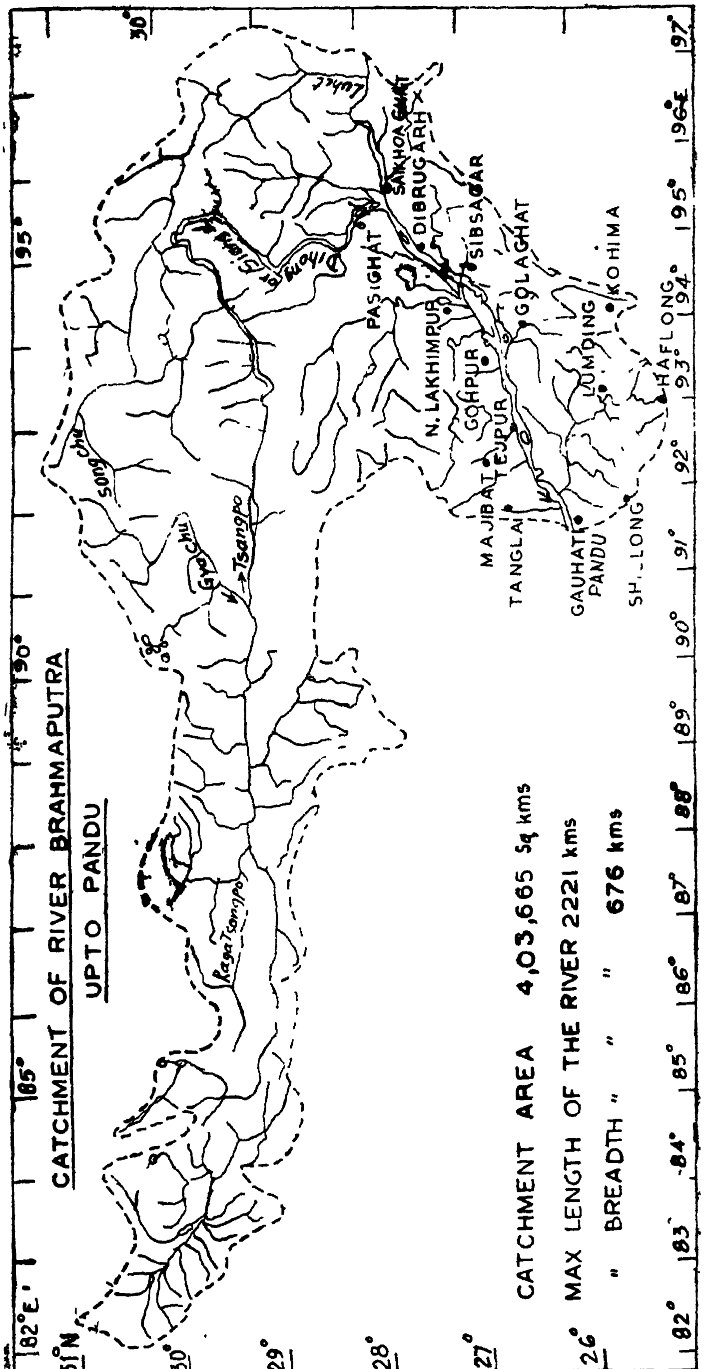
	Population
Population affected	413346
Lives Rescued Loss	11206
of life in Surat City	44
Surrounding Villages	35
Total	79
Cattle lost	554 Nos.
Houses damaged: Surat	4614 Nos.
Surrounding Villages	12919
Industries affected	All.
Total damage	Rs. 4,52,90,190/-

CASE No. 10

CATASTROPHIC FLOODS IN THE BRAHMAPUTRA IN AUGUST 1962

1. Introduction

In these floods, the peak rate of flow reached the very high figure of 72700 cubic metres per second at Pandu near Gauhati (Figure 10.1) on 24th August 1962. It is seen from the UNESCO publication (1976) entitled "World Catalogue of "Very Large Floods" that the peak discharge figure given above, is the third highest figure of peak discharge in any Indian river during the period for which data have been given in that publication.



CATCHMENT OF RIVER BRAHMAPUTRA
UPTO PANDU
CATCHMENT AREA 4,03,665 Sq kms
MAX LENGTH OF THE RIVER 2221 kms
" BREADTH " " " 676 kms
Tsangpo
Song chu
Gyachu
Raga Tsangpo
Siang
Dihang
Lohit
PASIGHAT
SAIKHOAGHAT
DIBRUGARH
SIBSAGAR
GOLAGHAT
KOHIMA
N. LAKHIMPUR
GOHPUR
TEJPUR
LUMDING
HAFLONG
MAJIBAT
TANGLA
GAUHATI
PANDU

Figure 10.1

A detailed paper on the synoptic aspects of these floods, with a large number of diagrams, has already been published (1979) by the author and his associate Vuddagiri Subba Rao. An important point brought out in that paper is that no attention had been given in the past to the fact that floods in the Brahmaputra can be caused not only by heavy rainfall over the catchment of the Brahmaputra proper (which lies within the Indian territory) but also by heavy rainfall over the Tsangpo which flows for about 1700 Km. from west to east to the north of the Himalayan range before the river enters India in the extreme northeast and is thereafter known by the name, Brahmaputra (Figure 10.1). No rainfall data pertaining to the Tsangpo were however available to the authors for their study. They had therefore to base their conclusions on the rainfall data of the 14 I. Met D stations in the Brahmaputra Basin upto Gauhati* and on the available synoptic charts.

In the same paper, another important point brought out is based on the experiments recently performed in the laboratory by Chinese scientists (1977) on simulation of the atmospheric flow patterns over and near the Tibetan Plateau. The actual flow patterns over the same area at the 500 mb. level as published by Japan Meteorological Agency during the period June to August 1962 have been discussed with reference to the simulated flow patterns observed in the laboratory. In the following paragraphs, details relating to these new aspects only have been discussed. The conclusions based on a study of the charts for the Indian sub-continent have been only briefly stated without going into the arguments which led to these conclusions For the same reason, we are not giving in this monograph, details regarding the study of the total precipitable water over the catchment of Brahmaputra Only the conclusions arrived at from our analysis have been given in the section on "Conclusions". If the reader is interested in further details, he is requested to refer to the original paper.

2. Rainfall Analysis

Table 10.1 contains the rainfall figures and statics relating thereto in respect of the 14 I.Met.D. Observatories in the catchment of the Brahmaputra for the period 1st June to 24th August, 1962.

It will be seen from the table that Pasighat in the extreme northeast of Arunachal Pradesh is the only station in the Brahmaputra basin (upto Gauhati) which recorded more than 250 mm of rainfall in 24 hours on 16 occasions during the above-mentioned period. The number of such occasions drops off to very low values at stations downstream of Pasighat. It is hardly necessary to point out that rainfall in Pasighat area alone could not have led to the phenomenal peak-discharge of 72700 cubic metres per second. Heavy rainfall must have occurred over a much larger area further upstream (i.e. in the catchment of the Tsangpo Figure. 10.1). And this is confirmed by the synoptic patterns which we shall discuss a little later.

*Gauhati is much better known than Pandu where river-discharge measurements are made. Hence, unless otherwise specifically stated it is to understood that whenever Gauhati is mentioned in this monograph, Pandu is actually being referred to, so far as discharge measurements are concerned.

Table 10 1. *Rainfall (mm) in 24 hours ending 03 GMT as recorded at I.Met D. Observatories over Brahmaputra Basin—1st June to 24th August, 1962.*

I.Met D. Observatory and its abbreviated symbol.	Coordinates of Station.	Highest recorded rainfall (mm)	Number of occasions when rainfall (mm) in 24 hrs occurred within specified limits				Number of occasions of 75 mm or more in 24 hours
			More than 250	249 to 200	199 to 150	149 to 75	
Pasighat (PSG)	28° 06′ 95° 23′	320.8	3	0	1	12	16
Dibrugarh (DBH)	27° 29′ 95° 01′	103 2	0	0	0	3	3
North Lakhimpur (LKR)	27° 14′ 94° 01′	119 0	0	0	0	3	7
Sibsagar (SBG)	26° 59′ 94° 38′	74.0	0	0	0	0	0
Tezpur (TZP)	26° 07′ 92° 47′	80.6	0	0	0	1	1
Gohpur (GHP)	26° 50′ 93° 35′	59 2	0	0	0	0	0
Golaghat (GLT)	26° 31′ 93° 59′	97.2	0	0	0	1	1
Majbat (MJT)	26° 45′ 92° 21′	235 0	0	1	0	3	4
Tangla (TNL)	26° 39′ 9!° 55′	59.0	0	0	0	0	0
Gauhati (GHT)	26° 06′ 91° 35′	66.8	0	0	0	0	0
Shillong (SHL)	25° 34′ 91° 53′	63 6	0	0	0	0	0
Lumding (LML)	25° 45′ 93° 11′	63 6	0	0	0	0	0
Kohima (KHM)	25° 38′ 93° 10′	104 6	0	0	0	2	2
Haflong (HFL)	25° 10′ 93° 01′	128 8	0	0	0	4	4

3. Large scale Synoptic Situation

An analysis of the daily synoptic situations during the months May to August 1962 suggests that the abnormal floods in the third week of August 1962 were not solely due to heavy rainfall during the 30-day period prior to the peak-discharge but was connected, however remotely, with the succession of spells of heavy rainfall one after the other from the last week of May 1962 to the third week of August 1962. The synoptic situations associated with these spells were :

a. Unusually early advance of the monsoon over the catchment of the river in May 1962; For details, the original paper of Ramaswamy and Subba Rao (1979) may be referred to.

b. Strong monsoon in June 1962 in association with a Bay of Bengal depression. Details have been given in the original paper referred to in (a) above.

c. Spell of strong monsoon over the Tsangpo betweeu 22nd and 28th June 1962;

Figure 10.2 shows the 500 mb. contours over southeast Asia on 22nd June 1962.

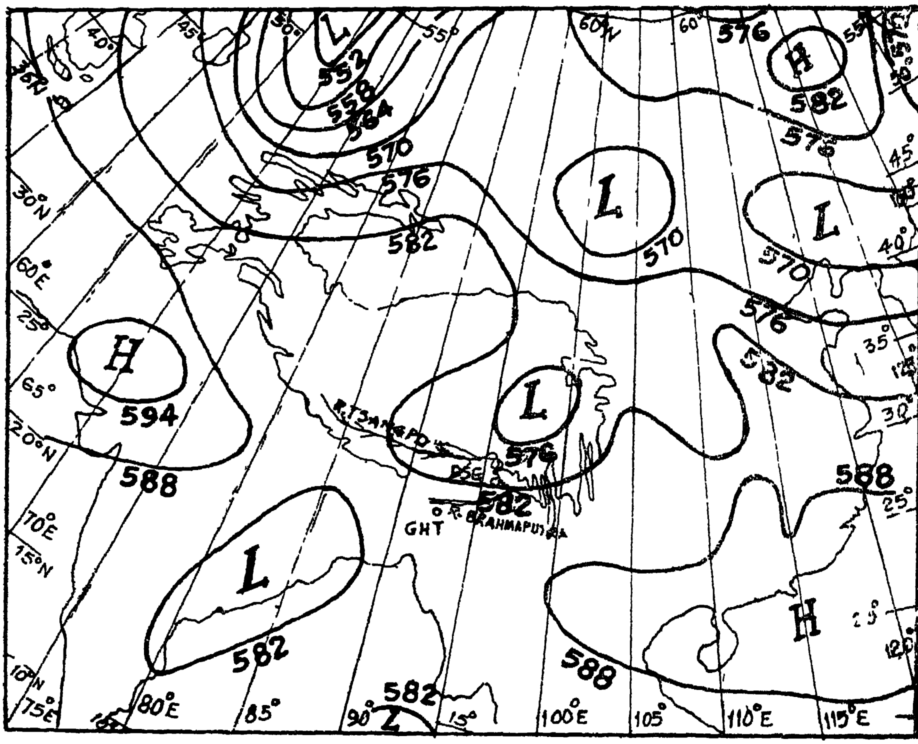


Figure 10 2 500 mb, 1200 GMT June 22, 1962

These have been reproduced from the charts published by the Japan Meteorological Agency. It will be noted that there is a deep low over the southeast corner of the Tibetan Plateau. The position of Pasighat and the course of the Tsangpo with reference to this deep low over the southeast of the Tibetan plateau may be particularly noted. As this cyclonic system to the southeast of the plateau will frequently be referred to in the later sections, we shall, for the sake of brevity refer to it as the cyclonic lee-vortex or simply as a "lee vortex". We may mention even at this stage that, in certain situations, a closed vortex does not exist but instead,,only, an open-trough. We shall refer to the latter as a "lee-trough". The genesis of the lee-vortex and lee-trough will be discussed in detail in one of the later sections.

The lee-vortex seen in Figure 10.2 caused very heavy rainfall over the Pasighat (PSG) region and possibly over the eastern half of the Tsangpo also. Figure 10.2 also shows a deep trough in the westerlies on 22nd June with its axis near 70°E. This trough later moved eastwards, increased in amplitude over the Tibetan plateau and moved away as a weak system over the Tsangpo and Arunachal Pradesh.

Figure 10.3 shows a time-section of the winds over Gauhati and of the heavy rainfall which occurred over Pasighat, North Lakhimpur and Majbat during the period 22nd to 28th June. The precipitation between 22nd and 24th was caused by the lee-vortex seen on the 500 mb. chart in Figure 10.2. The heavy rainfall between 24th and 28th was caused by the successive movement of the two troughs in the westerlies seen in the same diagram, and on the 500 mb. charts of the corresponding dates (not reproduced here).

(*d*) *Fairly active monsoon in the upper reaches of the river in the first weak of July 1962.*

Fairly active monsoon conditions prevailed over and near the Pasighat region in the first weak of July. The Japanese charts show that lee-troughs at the 500 mb. level contributed mostly to the development of the fairly active monsoon conditions.

(*e*) *Active monsoon in the last week of July 1962*

Quasi-break conditions prevailed over the country during this period. It may be mentioned that the Pasighat region lay during this spell at the periphery of a "lee-vortex" at the 500 mb level on several days.

(*f*) *The Monsoon during the first two weeks of August 1962*

The activity of the monsoon between 1st and 9th August was subdued. The activity however increased between 10th and 14th. The flow-patterns during the latter period corresponded to the schematic flow patterns published earlier by the author (Ramaswamy 1972).

(*g*) *Vigorous monsoon over Pasighat region and the eastern half of Tsangpo during the third week of August 1962.*

The third week of August is the crucial period in the activity of the mansoon over the Pasighat region and the eastern half of the Tsangpo. It was the activity during this period which contributed most to the peak-discharge at Gauhati on 24th August. We shall therefore go into this situation a little more in detail.

Table 10 2 shows the rainfall over the North Brahmaputra basin (i. e. along the foot of the Himalayas) as recorded at the I. Met. D. Observatories during the period 15th to 23rd August both days inclusive. Rainfall exceeding 75 mm. (in 24 hours) has been printed in the table in thick. print.

Table 10.2 clearly shows the following :

a) Rainfall exceeding 75 mm occurred only in Pasighat;

b) Rainfall abruptly increased over Pasighat on 16th and reached a maximum on 17th and 18th;

c) there was a sharp decrease in rainfall at almost every station after the 19th.

Table 10.3 shows the 24 hours rainfall (in mm) at representative stations on the west coast of the Peninsula, in the Deccan plateau, East Rajasthan, the central parts of the country and the east coast of the Peninsula between 16th and 23rd August 1962.

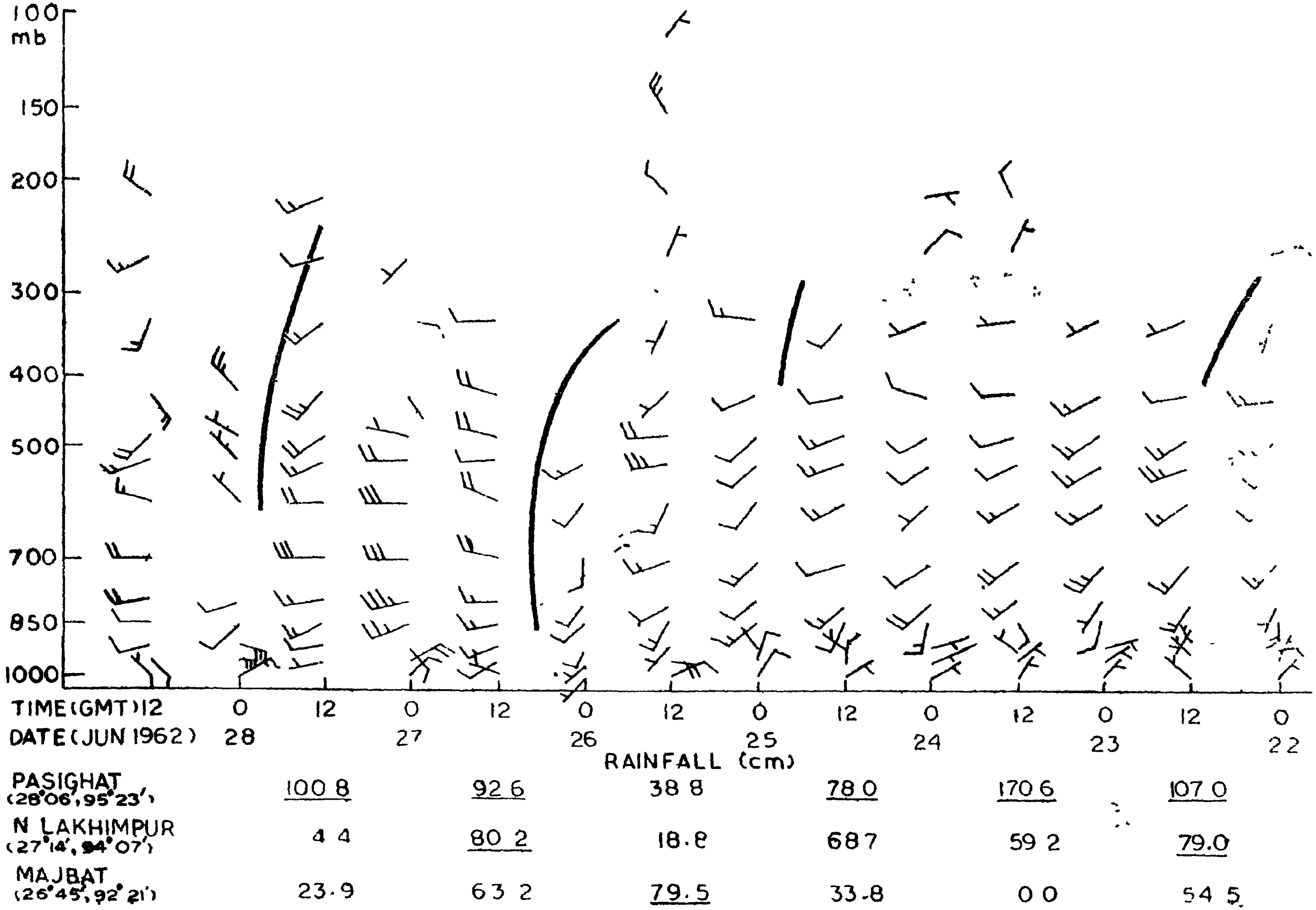


Figure 10.3 Vertical Time Section-Gauhati Heavy Rainfall Brahmaputra Catchment 22 June 1962 to 28 June 1962

Table 10 2. *Raınfall (mm) over North Brahmaputra Basin (ın Indıa) between 15th and 23rd August, 1962.*

(Peak-discharge at Gauhati—24th August, 1962)

Date August 1962	PSG	DBH	LKR	SEC	TZP	CHP	GLT	MJT	TNL	GHT
15	7 0	2 1	3 1	0 4	8 8	0 0	0.0	9 2	4 2	0.0
16	*122.0*	57 1	22.0	0.5	5 1	14 4	4 4	21 2	0.0	6.0
17	*320 8*	38.6	13.9	22.0	15 6	41.4	8·6	16 4	6.4	4 0
18	*311.6*	30 1	62 9	7.2	44.6	18.8	8 2	40 0	9.0	11.8
19	*259.7*	50 0	53 0	14.0	22 6	25 0	0.0	72 6	49.5	6.0
20	*105.8*	38.2	8.3	0.5	7.5	2 2	0.0	30 5	25.5	13.2
21	*76.6*	Trace	12 2	4.3	1.8	12 6	42 0	6.4	0 0	6.4
22	2.8	8 2	5 6	4 1	0 0	6 2	0 0	28.0	0 0	0 0
23	0.4	0 0	10 6	0 0	0 0	0 0	6.8	0 0	0 0	0 0

Table 10 3. *Raınfall (mm) ın 24 hours endıng at 0300 GMT ın August 1962.*

Date	West Coast			East Rajasthan			Decan Plateau	Central parts of country			East Coast	
	BMB	RTN	MNG	JPR	JLR	KTA	HYD	NGP	AKL	SNI	KND	VSK
16	5 1	18 5	84 6	0.0	51.6	2.0	0.0	36 0	4.1	28 7	68 0	0 0
17	16 9	4 6	69.9	0.8	3.6	3 0	1.3	20.3	1.0	61 4	116 0	8.3
18	0 2	10 4	12.2	0.0	0 0	1 6	0.6	0 1	20.4	6.6	—	0 4
19	10 6	10.2	43.0	16 6	14.8	1.4	0.0	0 0	2.6	0 4	5.2	10 4
20	0.9	6.2	3 8	0.0	0.0	5.0	1.2	2.5	0.7	0.0	0.0	0 0
21	5.0	8 0	0 0	0.0	0.0	0 0	1.4	0 0	0 0	2 2	0 0	22 3
22	7 6	8 0	0.0	0.0	0.0	0 0	0.0	0.0	0 0	0 0	41.8	0.0
23	0 6	2 4	1.1	0 0	0.0	0.0	0.0	0 0	0 0	0 0	0 0	7.1

Additional Comments :

03 GMT 18th : Barmer and Jodhpur ın the arıd zone ın West Rajasthan had reported respectively 61.5 mm and 10 mm of rain. Ajmer in East Raıasthan was having contınuous slıght rain at 03 GMT.

03 GMT 19th : Jodhpur ın West Rajasthan had reported 1 6 mm of rain

Table 10.3 and the additional information gıven at the bottom of the Table clearly show that almost all the stations had significant rainfall upto the morning of 19th and that the amounts sharply decreased on the 20th. The additional comments about other stations given at the bottom of the table may also be noted.

It may be recalled that the generally accepted criteria for declaration of a "break in the monsoon" are

a) sharp decrease in the rainfall over the central parts of the country;
b) significant decrease in rainfall on the West Coast and the northern half of the Deccan plateau;
c) no rainfall in semi-arid areas like East Rajasthan and certainly no rainfall in an arid zone like West Rajasthan;
d) disappearance of easterlies at the surface and below 1.0 km over the Gangetic plain.

None of the criteria given above were satisfied upto 19th August. *We therefore arrive at the importent conclusion that large-scale break-situation developed over the country only on and after the morning of 19th August.*

Turning our attention again to Table 10.3 we are of the opinion that if a break-situation had been responsible for heavy rainfall over Pasighat, the rainfall over that station and other stations in that Table should have increased after 19th. It was, however, just the opposite showing thereby that the exceptionally heavy rainfall over the Pasighat region and the significant amounts of rainfall at other stations in the North Brahmaputra basin, between 16th and 19th were not associated with break-conditions in the monsoon but with some other system. What this other system was, may be seen in the 12 GMT 500 mb. level Japanese charts for 17th August in Figure 10.4. It will be seen from this diagram that there was a west to east oriented lee-vortex over the southeast of the Tibetan plateau on 17th. The course of the Tsangpo and the position of Pasighat (PSG) with reference to this "lee-vortex" may be noted.

The trough in the westerlies with its axis between 65E and 70E on 17th August vide Figure 10.4 began to move eastwards as a separate entity. The main system moved to the north of the Tibetan plateau. But a "Low" developed to the south of the Tibetan plateau on 18th August, moved eastward along the foot of the Himalayas and crossed Arunachal Pradesh on 20th August. This low was responsible for the rainfall of 76.6 mm. reported by Pasighat on the morning of 21st August vide Table 10.2.

It is interesting to note that the Japanese charts for the 500 mb. level did not contain even a feeble indication of a lee-vortex or a lee-trough over or near the Pasighat region on the 12 GMT charts of 21st. This is considered as significant because the rainfall over Pasighat region sharply decreased after the morning of 21st.

We conclude from the above analysis *that the factor which contributed most to the exceptionally heavy rainfall over Pasighat between 16th and 20th was the lee-vortex and that the wave in the westerlies and the break-situation in the monsoon played a very secondary role in the production of very heavy rainfall over the Pasighat region.* We also infer from this analysis that the very heavy rainfall which had occurred between 16th and 20th would have considerably swollen the eastern half of the Tsangpo river and the Brahmaputra near Pasighat where the river was already in high

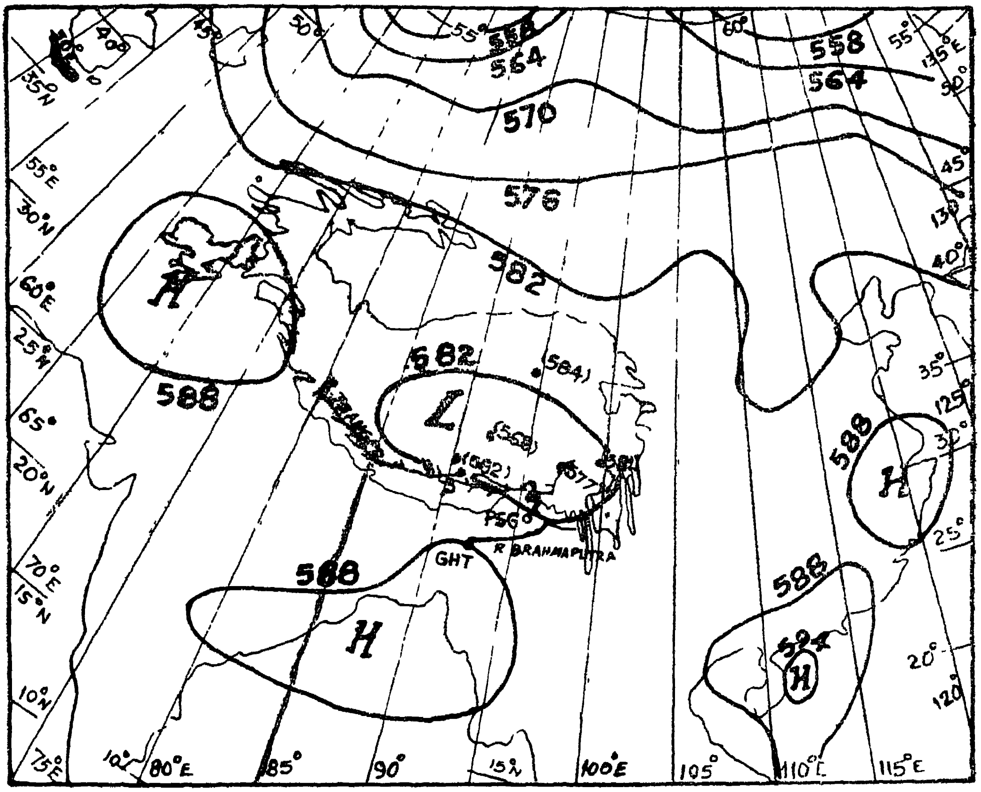


Figure 10.4 500 mb 1200 GMT August 17, 19б2

flood. These remarkable development would have led to the observed peak-discharge at Gauhati (Pandu) on 24th August.

4. Genesis of the lee vortex to the Southeast of the Tibetan Plateau

In a very interesting paper published in the January—February 1977 issue of "Scientia Sinica" a group of 10 Chinese scientists (Li Kuo-Ching et al 1977) have reported on an experimental simulation of the atmosphere over and near the Chinghai-Tibetan plateau. They have simulated atmospheric motion by fixing a model plateau inside a body of rotating fluid, heating the model-plateau wholly or in different parts, using different Roseby numbers and controlling the rate of motion of the rotating fluid. Their findings are briefly summarised below so far as they are relevant to our present investigation :

(a) In th case of a non-heated model plateau, and high Rossby numbers, only lee-troughs form to the southeast of the model plateau. No vortices form under such conditions.

(b) As the plateau is progressively heated but below a certain limit, there is a greater and greater tendency for the formation of lee-vortices to the southeast of the model-plateau. *These vortices are not ordinary heat-lows as they are not formed over the heating source and are much smaller than the heat-lows.*

(c) With low Rossby numbers, lee-troughs extend westwards to form a WSW-ENE oriented tilted trough which may reach as far as North Bay of Bengal as in the actual weather charts prepared in China. Along this tilted trough, vortices are frequently formed.

(d) The value of the Rossby number is of great importance in determining the formation of Lee-vortices and their structure.

(e) The vortices are more pronounced with weak basic westerlies then with strong basic westerlies over and around the plateau. Consequently, the lee-vortices are more pronounced in conditions corresponding to June than in April or January.

(f) The lateral extent of the simulated lee-vortices is 400-1000 km at the 700 mb. level. Thus, they are of the same order of magnitude as have been actually observed on the Chinese synoptic charts.

(g) Simulated vortices which form to the west of the. Tibetan plateau get decelerated as they move eastward. They also become diffuse and lose their identity by the time they cross the model plateau. However, when these vortices to the west of the plateau are deep enough, they can cross the plateau and then they regenerate over and near the Tienshan range.

(h) As the experiments are still of a preliminary nature, it would be incorrect to assume at this stage that the simulated motion would agree in all respects with the motion actually observed in the atmosphere over and around the Chinghai-Tibetan plateau.

5. Importance of the lee-vortex in the Development of Floods in the Brahmaputra Basin

The laboratory experiments performed by Li-Kuo Ching et al and schematic patterns published by these Chinese scientists of the simulated vortices are of great interest to

us from the point of view of the development of heavy rainfall near the Pasighta region and further upstream i.e., over the river Tsangpo.

From the literature referred to above and from our study of the 500 mb. charts published by the Japan Meteorological Agency for 1962 and charts for the Indian subcontinent prepared in the I. Met. D., we arrive at the following general conclusions:—

(a) the lee-vortices actually observed at the 500 mb level to the southeast of the Tibetan plateau are quasistationary in character. The mean position of the centre of the lee-vortices at the 500 mb level in June, July and August 1962 is 31-32N and 97-98E. Their lateral extent at the same level is about 4000 to 1000 Km. i.e., of the same order of magnitude as that found by the Chinese scientists in their laboratory experiments.

(b) The lee-vortices play an importont role in the development of weather over the Pasighat region and the eastern half of the Tsangpo when they are in the appropriate position.

6. Conclusions

Based on on the above detailed study, we arrive at the following conclusions :—

(a) The very large floods which occurred in the Brahmaputra in August 1962 were due to exceptionally heavy rainfall over the extreme northest of Arunachal Pradesh and (by inference) over the eastern half of the Tasngpo.

(b) The lee-vortex observed by us at the 500 mb level, is essentially the same as the one generated to the southeast of the Tibetan Plateau in the simulation experiments of the atmosphere conducted by Chinese scientists.

(c) The lee-vortex contributed far more to the development of heavy rainfall over the Pasighat region and the eastern half of the Tsangpo in the monsoon season of 1962 than any other single factor such as quick succession of northeastward moving low pressure systems from the Bay of Bengal, eastward moving waves in the westerlies and breaksituation in the monsoon.

(d) A study of the large-scale synoptic systems to the north of and northeast of Arunachal Pradesh on a day-to-day basis is "a must" if we are to issue reasonably accurate forecasts of heavy rainfall which have their origin in the upper reaches of the Brahmaputra and over the Tsangpo. In particular, the synoptic climatology of the above-mentioned region at the 700 and 500 mb levels with special reference to weather over the Brahmaputra basin must be developed and used in day-to-day synoptic practice.

(e) While we do not under-estimate the importance of the systems which led to the antecedent precipitation during the 30-days prior to the peak-discharge on 24th August, we are of the opinion that weather systems right from the time of onset of the monsoon must have played a role, however minor, in the development of very high floods in the Brahmaputra in August 1962.

(f) In Arunachal Pradesh and elsewhere in Assam, there is enough precipitable water to cause very heavy rainfall over those areas during the southwest monsoon period.

7 Flood Damage

The widespread floods caused enormous damage to life and property. In Assam (for third time since the beginning of the monsoon season) all rail and road communications were distrupted for days together. Dibrugarh town was submerged and low lying areas of Gauhati town were inundated. The area behind the aerodrome terminal building and the meteorological office at the Gauhati airport was under 2 to 5 feet of water. Army had to be called out to take up relief and rescue work. The worst flood affected districts of Assam were Lakshimpur, Sibsagar, Darang, Kamrup and Goalpara. In West Bengal, the districts of Jalpaiguri and Cooch-Bihar were the worst hit by floods. In Bihar 152 heads of cattle and standing crops over vast areas were washed away.

CASE No. 11

CATASTROPHIC FLOODS IN THE BRAHMAPUTRA AND IN THE RIVERS IN SOUTH ASSAM IN JUNE 1966

1. Introduction

This is the first case we are presenting about catastrophic floods in the Brahmaputra and in the rivers in South Assam in the month of June; the very first month in the southwest monsoon season. Although we had earlier presented an account of the castastrophic floods in the Brahmaputra in the month of August, 1962 (Case No. 10) the present case is of very special interest, as *severe floods occurred in the Upper reaches of the river in the first half of June.* This development did not take place either in association with the northeastward movement of a cyclonic system from the Bay of Bengal or with the shifting of the monsoon trough to the foot of the Eastern Himalayas. In other words, two of the important "accepted" mechanisms for heavy rainfall leading to severe floods in Assam, were absent on this particular occasion. What then caused the severe floods in the upper reaches of the Brahmaputra so soon

after the monsoon had advanced into that area ? We shall attempt to answer this question in this Section.

2. Hydrological Information

According to an I. Met. D. publication (1967) the high flood level at Dholla on the Brahmaputra, surpassed all previous records with a gauge-reading of 424.78 feet on 7 June 1966 and Dibrugarh recorded a level of 343.5 feet against the danger level of 342.0 feet. The level of the river Barak (South Assam) on 12 June was 21.02 metres as against the danger level of 19.87 m).

As we shall see a little later, the monsoon advanced into Assam on 4th June. The important fact that the flood level rose at the above-mentioned gauging stations within a few days of the onset of the monsoon may be particularly noted.

3. Mean Circulation-Patterns in June

The mean stream-lines at the 500 mb level over Northeast India and the Tibetan plateau in June as delineated by Ramage and Raman (1972) in the Meteorological Atlas of the International Indian Ocean Expendition clearly show that the mean circulation is *westerly* at this level. Their streamline chart also reveals a well-marked *mean* trough in the Westerlies with its axis running roughly from NW to SE and passing to the east of Calcutta.

Figure 11.1 shows the mean monthly contour pattern over India at the 300 mb level in June drawn by the author. It will be seen that the mean circulation at the 300 mb level is also *westerly* even upto 27°N and that the axis of the mean trough in the westerlies runs along 85°E approximately. This picture is reasonably consistent with the stream lines drawn by Ramage & Raman (1972) at the 300 mb level.

4. Pre-Monsoon Thunderstorm Activity in Assam in 1966 :

The thunderstorm activity in Assam was poor in April and May 1966. This is brought out conspicuously by Table 11.1 which contains weekly figures of excess and defect in rainfall in North Assam (including NEFA) and in South Assam (including Nagaland, Manipur, and Tripura) during the period April to June 1966. It will be seen that the weekly rainfall in both North and South Assam was in moderate to large defect upto 25 May 1966. The situation later somewhat improved but even then the activity had only just become normal by 1st June vide Table 11.1. And as we shall see a little later, the monsoon advanced into Assam on 4th June i e. three days later. In view of these facts, it is difficult for us to accept the view expressed elsewhere (I. Met. D., 1967) that there was "good pre-monsoon thunderstorm activity" and "persistent heavy rains" in Assam before the onset of the monsoon.

5. The Onset of the Monsoon in Assam in June 1966

It is usually difficult to decide about the date of onset of the monsoon in Assam. However, in June 1966, it was comparatively easy to see that the southwest monsoon

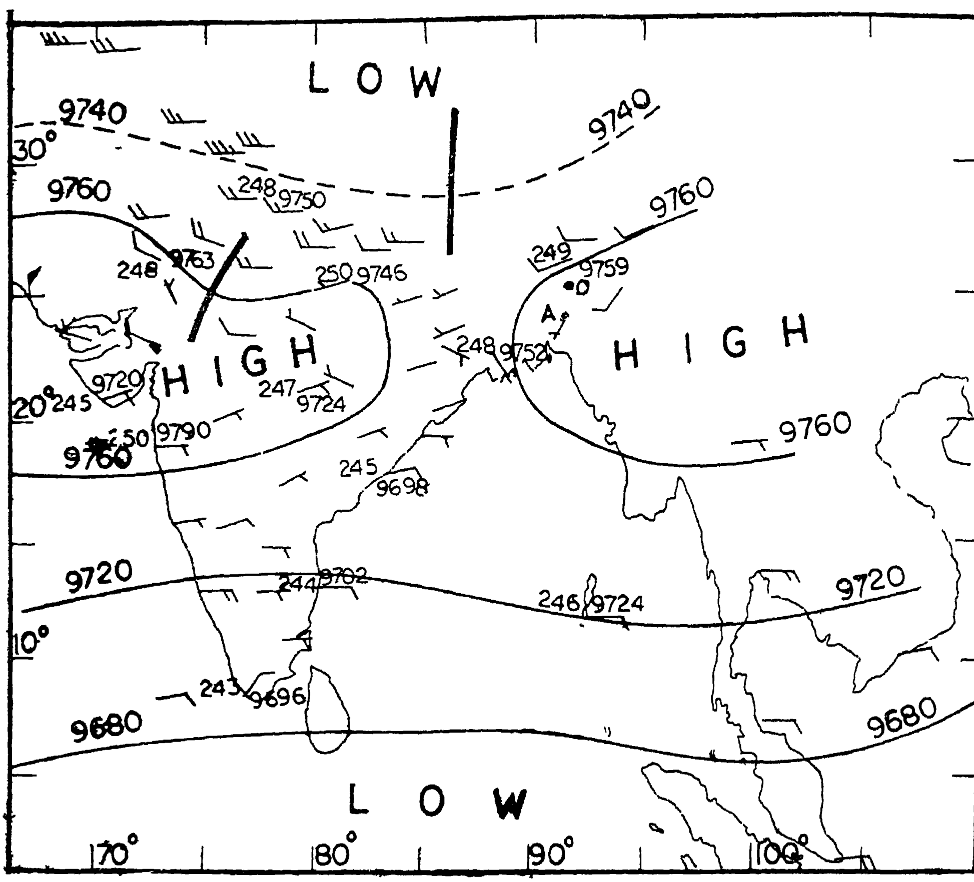


Figure 11.1 Normal 300 Mb Contours June

had advanced into the State after 03 GMT on 4 June. This development took place in association with a depression which had developed in Central Bay of Bengal by 12 GMT of 2 June and crossed the Andhra coast near Kalingapatnam by the evening of 3rd. The sea level isobar indicated that the monsoon air in the south and east quadrants of the depression had penetrated into Assam by the morning of 4th.

6. The "Lee Vortex" and its Contribution to Vigorous Monsoon over the Nefa Region and the Eastern Half of the Tsangpo

Table 11.2 shows the daily rainfall over Assam between 2 and 10 June. All the observations shown in Table 11.2 except those of Pasighat were taken from the published Indian Daily Weather Reports. The data for Pasighat alone were therefore obtained by post from the National Data Collecting Centre at Pune. The observations from the other stations were got checked by necessary correspondence with Weather Centre at Pune.

Table 11.1 *Extract fram I.Met. D. Weekly Weather Reports—April-June 1966 Actual and Excess or Defect in rainfall (mm) Wəels ending on*

Sub-Division	27 April	4 May	11 May	18 May	25 May	1 June	8 June	15 June	22 June
North Assam	27	25	30	6	31	85	171	171	25
(including NEFA)	—11	—50	—59	—80	—46	5	98	65	—101
South Assam (including NAGALAND, MANIPUR &	49	10	125	9	29	126	104	131	145
TRIPURA)	0	—57	34	—77	—58	28	—7	—19	8

Note :—The upper figures against each sub-division give the *actual* rainfall in mm. The corresponding lower figures give the excess or defect in rainfall, also in *mm.*

Table 11.2 *24 hours Daily rainfall (mm) as published in Indian Daily Weather Report—June 1966*

Pasighat (NEFA) (28°' 06N, 95°' 23E)	70	23	132	113	189	191	74	158	71
Mohanbari (27° 29'N, 95° 01'E)	08	41	59	27	09	13	33	82	154
Sibsagar (26° 59'N, 94° 38'E)	05	29	25	06	0	05	02	14	35
Tezpur (26° 37'N, 92° 47'E)	00	00	11	00	04	14	22	42	44
Gauhati (26° 06'N, 91° 35E)	11	00	04	19	01	11	45	17	20
Dhubri (26° 01'N, 89° 59E')	185	03	22	16	87	59	13	00	06
Silchar (24° 49'N, 92° 48'E)	19	06	29	48	22	17	98	45	124
Tura (25° 31'N, 90° 14'E)	74	00	19	18	101	09	03	00	00
Imphal (24° 52'N. 93° 55,E)	00	09	29	01	17	01	25	29	53
Agartala (23° 53'N, 91° 15'E)	01	00	08	28	04	00	00	00	00

Rainfall which was 70 mm or more in 24 hours have been indicated in bold face in Table 11.2. It will be seen that there was very heavy rain over Pasighat day after day between 4th and 11th. In contrast, rainfall was very much less at almost all the other stations during the same period even after making allowance for a few mistakes on the part of the observers in reporting.

Figures 11.2, 11.3 and 11.4 show the contour patterns on 4, 5 and 6 June 1966, to the north of India at the 500 mb level. This level lies well-above the mean altitude of the Tibetan plateau. The charts for the above mentioned three dates have been given only by way of illustrations. L_4, L_5, L_6 indicate the centres of the systems on the corresponding dates. It will be seen from the above-mentioned diagrams that a quasi-stationary lee-vortex* (Ramaswamy and Subba Rao, 1979) lay over or near

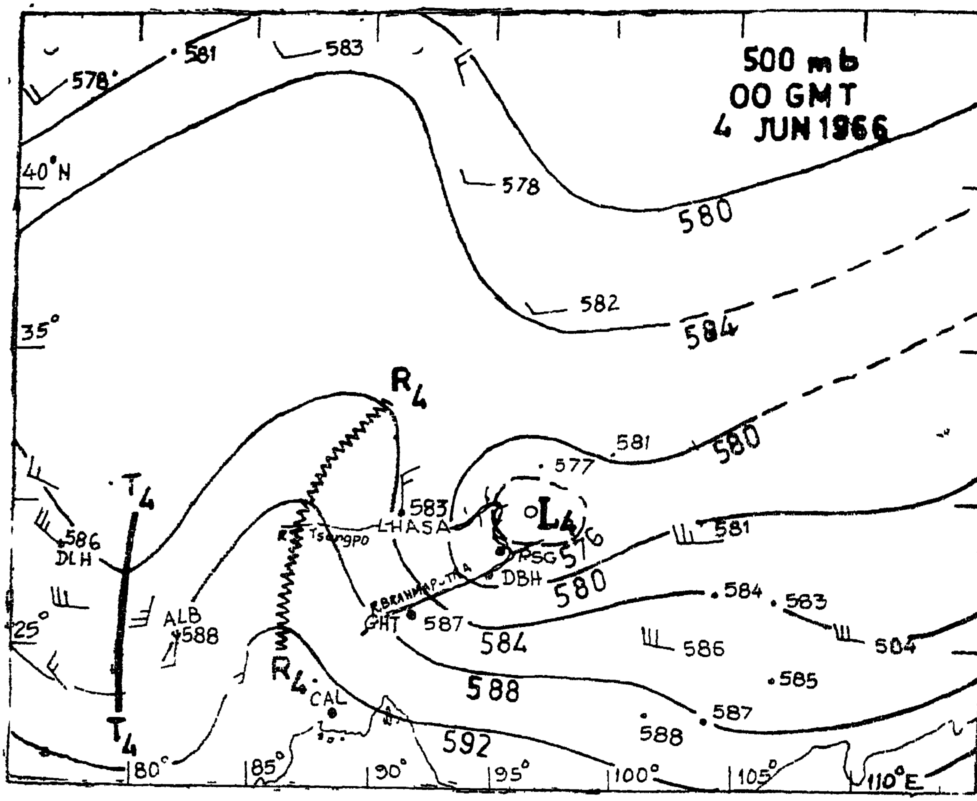


Figure 11.2

*The rainfall of 70 mm reported by Pasighat and 185 mm by Dhubri on the morning of 2 June 1966 was not associated with a lee-vortex. It was caused by high level divergence ahead of the axis of a wave-trough in the westerlies (Ramaswamy, 1956). The upper winds at the 500 mb level at 00 GMT on 1 June 1966 were : W 20 K over New Delhi 10k over Lhasa, SW 15K over Nagan and NW 30K over Ganzi. The contour corresponding to 5800 m. fits in well with this data.

In this connection, our discussion of the 110E Atlas of Ramage and Raman in an earlier paragra ph is relevant.

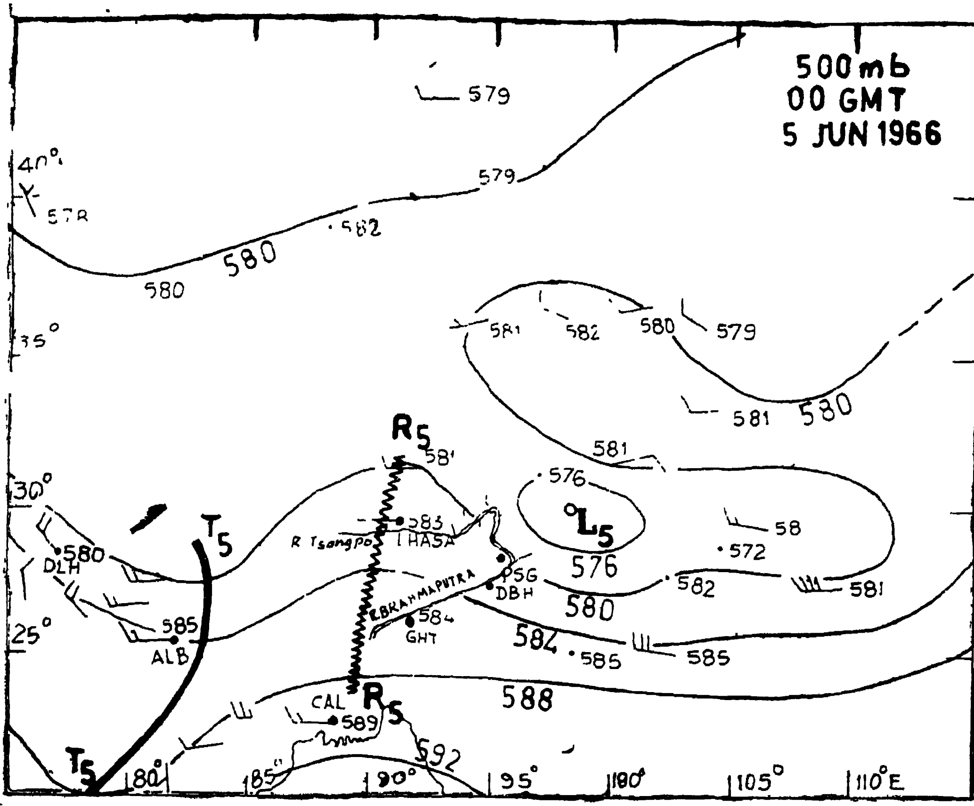


Figure 11.3

the NEFA region The positions of Pasighat (PSG) and Lhasa and the *westnorth-westward* movement of the lee-vortex between 5 and 6 June may be particularly noted. It is interesting to observe that the rainfall was very high over Pasighat between 4th and 9th.

Figures 11.5 and 11.6 show all the stations within the rectangular frame-work (15°N to 35°N and 80°E to 112°E) which were reporting "Present Weather" at 00 GMT on 5th and 6th. It is very significant that all the present weather remarks as seen in these two diagrams are to the east of 90°E and none to the west of that longitude. This gives further support to our analysis presented in the earlier paragraphs.

We thus come to the important conclusion that the severe floods in the upper reaches of the Brahmaputra in the case under study were caused by a quasi-stationary lee-vortex superposed on the monsoon air in the lowermost layers in the troposphere over NEFA and possibly also over the eastern half of the Tsangpo. We are unable

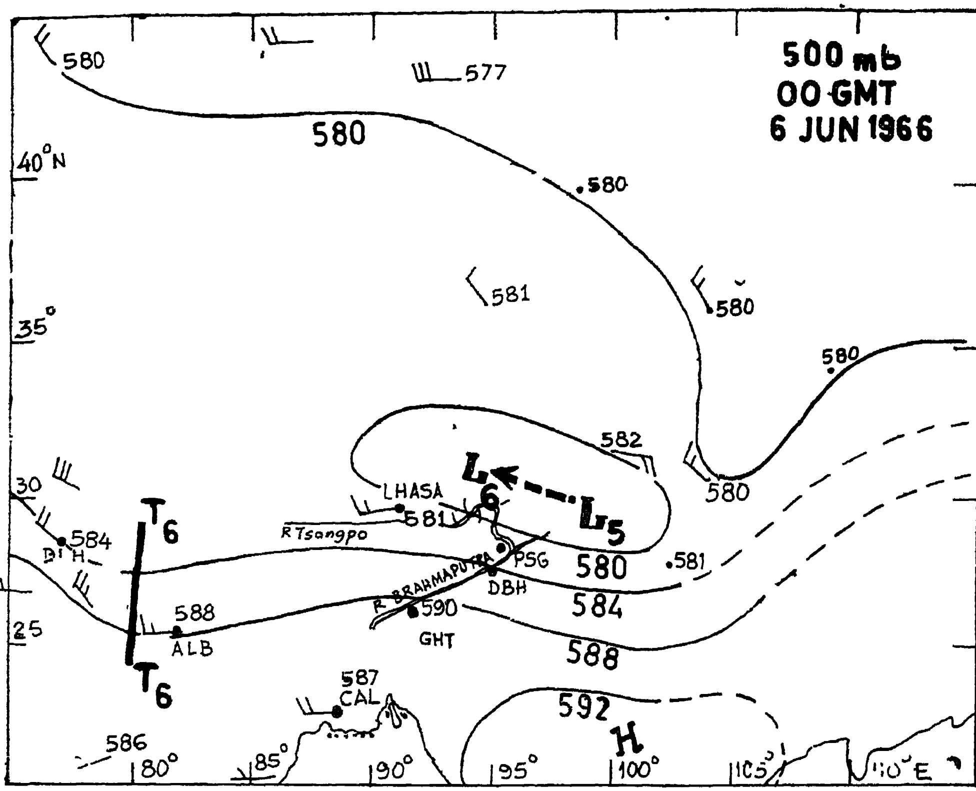


Figure 11 4

to probe more deeply into mechanism of the heavy rainfall owing to lack of observatons especially over the Tibetan plateau and along the banks of the Tsangpo. It is true that Pasighat itself is a plain-station at an altitude of only 157 metres asl. but one station is not enough if we are to study the problem in depth.

7. Vigorous Monsoon in South Assam in the Third Week of June 1966

This development was of the conventional type associated with the eastnortheastward movement from the North Bay of Bengal. The track of the depression may be seen in Figure 11.7. The vertical extent of the circulation associated with this depression did not extend above the 5oo mb level. The 300 mb level appeared to lie above the field of the depression. The estimated lowest central pressure in the monsoon depression was 994 mb and the corresponding departure from normal was minus 5 mb at 1730 hrs I. S.T. on 16th.

Without going into further details, we would state that the monthly mean 300 mb contour pattern in June shown in Figure 11.1 and monthly mean 200 mb counter

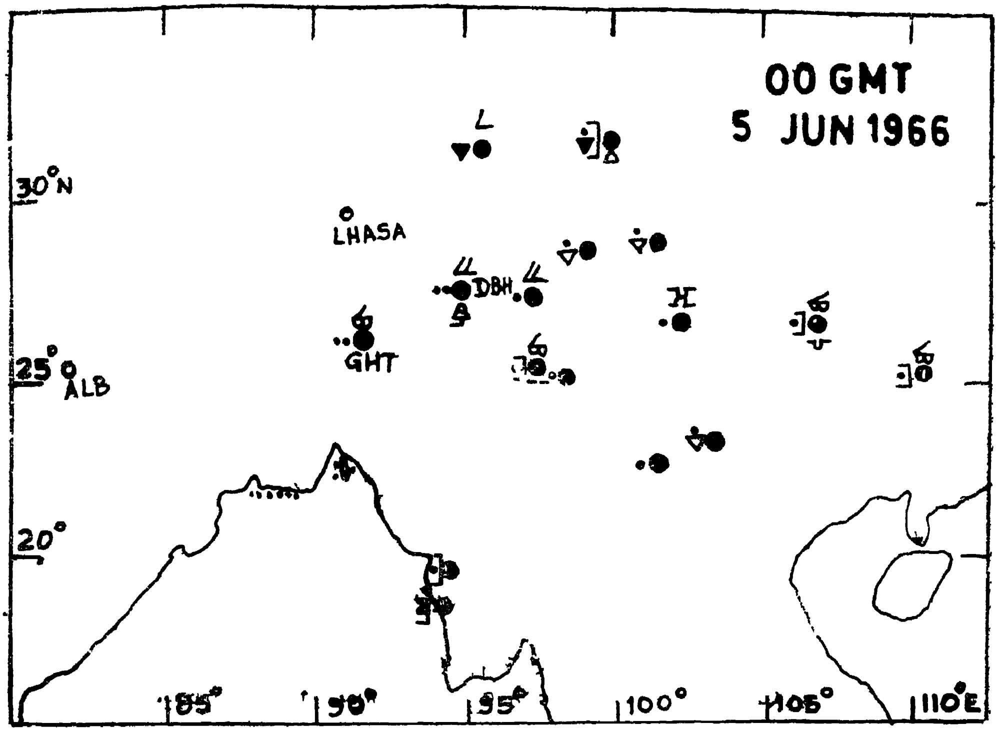


Figure 11 5 Present Weather Remarks

pattern in June (not reproduced here) throws light on the direction of movement of the depression from the head of the Bay of Bengal, initially northwards and later eastnortheastwards (around the periphery of anticyclone over Burma).

The noteworthy amounts of rainfall recorded at the I. Met. D. Observatory stations in the field of the monsoon depression as published by I. Met. D. (1967) were Agartala (Tripura State) 13 cm on 18th and Kohima 10 cm and Imphal 8 cm on 19th.

8. General Conclusions

By far the most important conclusion reached in this study is that the lee-vortex is potent enongh to cause very heavy rainfall in the upper reaches of the Brahmaputra even at the beginning of the monsoon season i. e. before the monsoon trough gets established at sea-level over the Gangetic plain.

The next important conclusion which comes out of our present study is that heavy rainfall produced by the depression from the Bay of Bengal occurred in the rivers in South Assam very soon after flood-waters from the Tsangpo and NEFA regions reached downstream in the Brahmaputra Basin. It is the combined effect of these two systems—the lee-vortex and the monsoon depression—that led to catas-

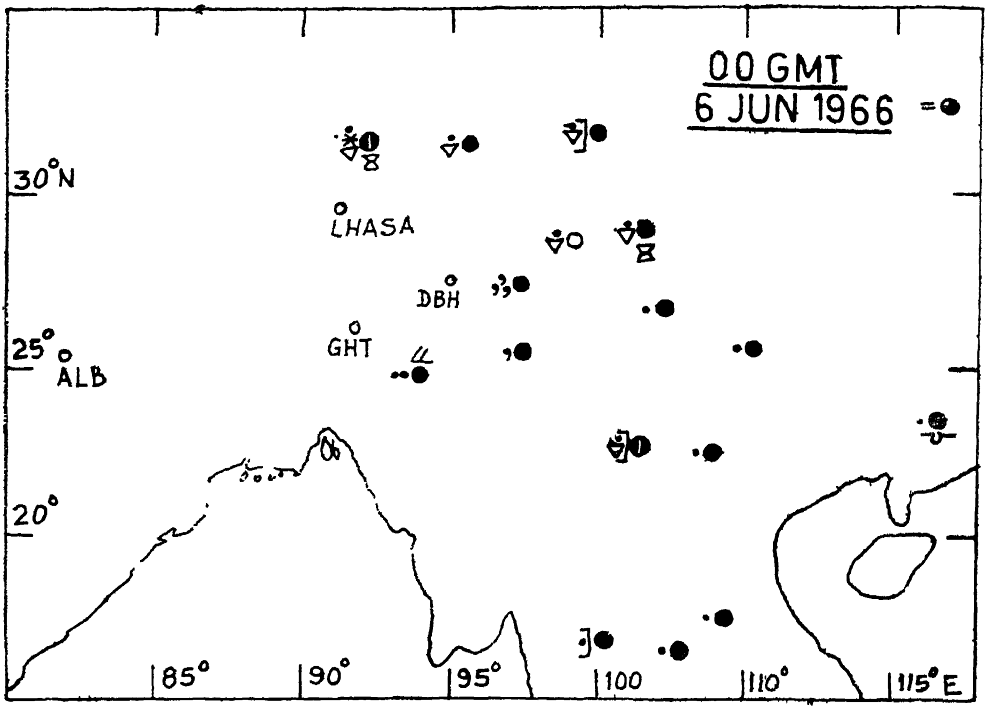


Figure 11.6 Present Weather Remarks

trophic floods in the whole of Assam. The havoc caused by the lee-vortex in North Assam appears to have been greater.

In conclusion, we would state that our study has once again (Ramaswamy and Subba Rao 1979) brought out the importance of the observations of Pasighat in NEFA. *Unless observations from this station are available to the forecaster, it will be extremely difficult for him in similar situations in future to predict well-ahead the severe floods in the upper reaches of the Brahmaputra.*

9. Flood Damage

The damage caused by the floods in the Brahmaputra Basin was very heavy. Communications between Assam and the other parts of the country were cut off. According to an All India Radio Report of 15 June, 1966, about 7 lakh people were affected by the floods. 80 per cent of cultivated land was damaged and 12 people lost their lives. Several embankments and dykes in Nowgong, Sibsagar and Darrang districts were breached and roads were submerged.

As a result of heavy rain in South Assam caused by the depression from the Bay of Bengal in the third week, vast areas of Silchar and Karimganj districts were flooded. It was reported that 80 per cent of the crops had been damaged in Cachars

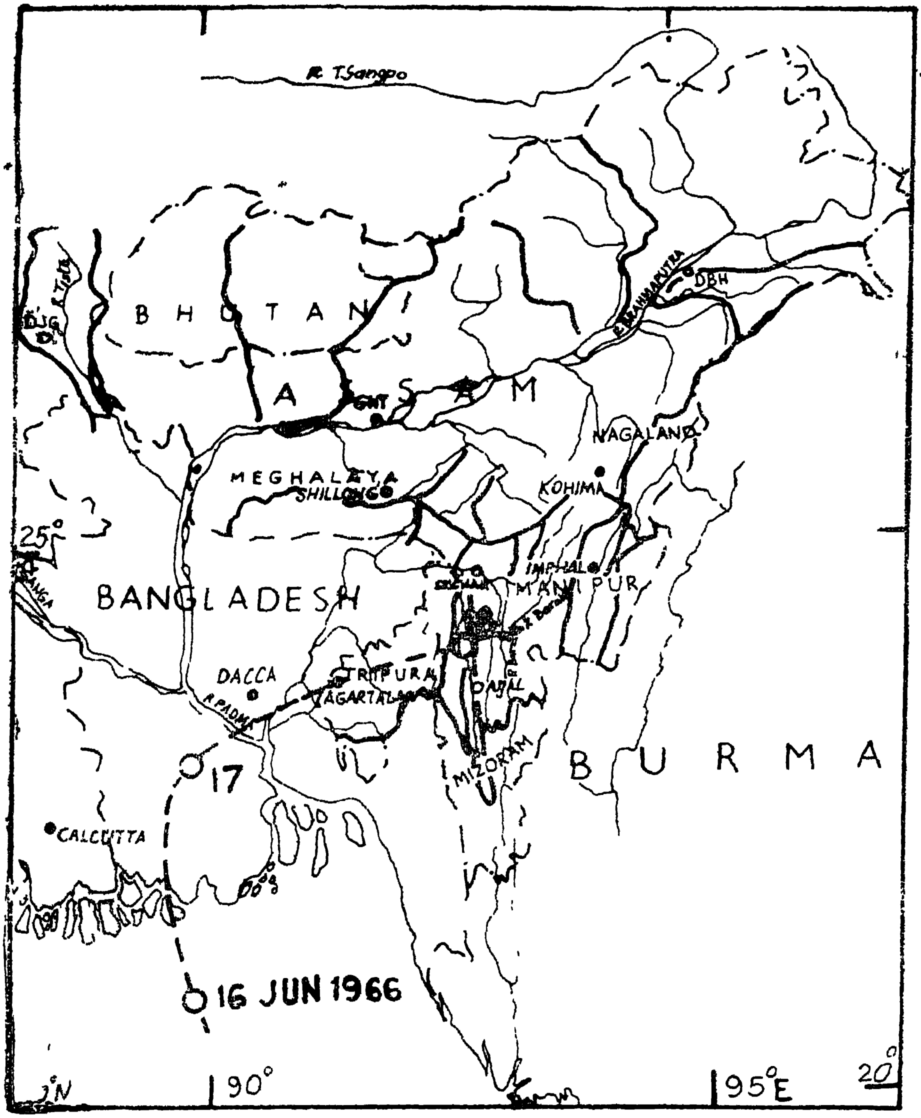


Figure 11 7 Track of Bay of Bengal Depression 16-18 Jun '66 and Catchments of Rivers

district and there were as many as 61 cuts and breaches of embankments in Silchar district alone. Land air routes linking Imphal with the rest of the country had been dislocated. It was reported that 3,38,000 people had been affected and 1000 heads of cattle had been lost in Manipur.

The total damage caused by the floods in the State of Assam as a whole, was estimated at Rs. 33 crores.

CASE No. 12

CATASTROPHIC FLOODS IN THE TISTA (A TRIBUTARY OF THE BRAHMAPUTRA) IN OCTOBER 1968

1. Introduction

The present case is one of the most important cases discussed in this monograph. In fact, it wasthe importance of this case that made the UNESCO publish a case-study of these floods as an illustration in one of their circulars vide Appendix III to V to Annex III of UNESCO circular No. SC/IHD/vi/25. The basic material for the UNESCO paper had been provided by the former Central Water and Power Commission of the Government of India.

The hydrometeorological aspects of these floods have been studied by Abbi, Gupta and Jain (1970). A study of the storm-rainfall over North Bengal river basins had also been undertaken by Gupta and Abbi (1972).

The meteorological aspects of these floods had been studied by the author of this monograph sometime ago making use of the daily synoptic maps prepared at the Northern Hemisphere Analysis Centre at New Delhi and various other publications of the India Meteorological Department. A brief summary of the tentative analysis made by him has already been published by him and Subba Rao (1977).

The present paper is an amplification of the tentative analysis over India and to the north of India upto middle latitudes. This opportunity had also been taken by the authors to utilise the printed Northern Hemisphere charts for October 1968 published by the Hydrometeorogical Service of U. S.S.R. Weather Satellite pictures have also been utilised in this study. This additional material which had been available has given the author more confidence in his analysis.

2. Hydrological Information

The following information about the magnitude of the flood has been taken from the UNESCO circular referred to above. It is more or less a quotation from the UNESCO circular.

"In most of the gauging stations, it was not possible to observe the actual flood level especially at *night* due to the sudden and unexpectedly high levels attained. The high flood level (HFL) crossed the "danger levels" by 20.4 m. (67 feet) at Anderson Bridge, 4 m. (13 feet) at the railway bridge near Sivok, and by about a meter at the embankments near Jalpaiguri Railway bridge. At Domohani, on the left bank of the river Tista, opposite Jalpaiguri, the river rose to 292.8 ft. in the early hours of October 5 overstepping and breaching the embankments at two places and water rushed to Domohani Bazar, damaging Jalpaiguri Town, and endangering transport on National Highway No. 31.

The peak discharge of the Tista river at Jalpaiguri bridge had been estimated as 18,745 cumecs.

The flood hydrograph as recorded at the gauging station at King's Ghat near Jalpaiguri may be seen in Figure 12.8.

3 Large-scale Synoptic Situation

Two large-scale weather systems were mainly responsible for the disastrous floods. They are described below in some detail.

3.1 First Weather System

This was a cyclonic storm from the Bay of Bengal. It was initially a severe one. It crossed the north Andhra coast near Kalingapatnam during the forenoon of 2 October (Figure 12.1). The storm was at its maximum intensity on 2nd morning. It persisted as a cyclonic storm at 0830 IST of 3 October when it was centred near Titilagarh (20°18′N, 83°18′ E) in Orissa. The circulation extended upto 300 mb level on the 3rd. The pressure-deficiency at the centre of the system when it was near Titilagarh was about 13.4 millibars. It is however important to bear in mind that there was a general negative pressure deficiency of about 6 millibars all over Northern India and the Central parts of the country on the morning of 3 October. It will therefore not be incorrect to state that the *effictive negative pressure-deficiency at the centre of the cyclonic system on the morning of 3 October was only about 7 milibars.*

While this was the position on the morning of 3 October the westerly circulation and the perturbations associated with it had already made the Bay of Bengal system begin to curve northwards. The cyclonic storm meanwhile weakened into a depression and continued to move northwards and was centred near Arrah (25°34′N, 84°40′E) as a depression in the plains of Bihar at 12 GMT of 4 October. *By the next morning (i. e. by the morning of 5th) the depression had completely degenerated into a diffuse low pressure area. The pressure deficiency had also virtually become nil.* The track of this Bay of Bengal Tropical cyclonic system and its intensity at different stages (shown according to the usual convention) may be seen in Figure 12.1. The catchment of the Tista is also shown on the same chart for facility of ready comparison. A diagram of the Tista catchment on a large-scale as published by the UNESCO may be seen in Figure 12.2.

3.2 Second weather System

As far as the author is aware, there is no reference to this system anywhere else in the earlier literature except in the article published by the author and Subba Rao in 1977 and referred to in the section entitled 'Introduction'. *This was an entirely independent system* in the westerly circulation at the 500 mb level and higher levels and it was quasi-stationary in nature. The complete contour patterns at the 500 and 300 mb levels at 1200 GMT on 4th and at 500 mb level at 00 GMT on 5th October may be seen in Figures 12.3, 12.4 and 12.5. Figure 12.6 shows the successive positions of the axis of the trough in the westerlies at 500 and 300 mb levels between 3 and 5 October. The suffixes indicated at the end of the trough-axis are self-explanatory.

Abbi et al (1970) have pointed out that the maximum rainfall over the Tista catchment occurred between the afternoon of 4th morning (03) GMT of 5th. During

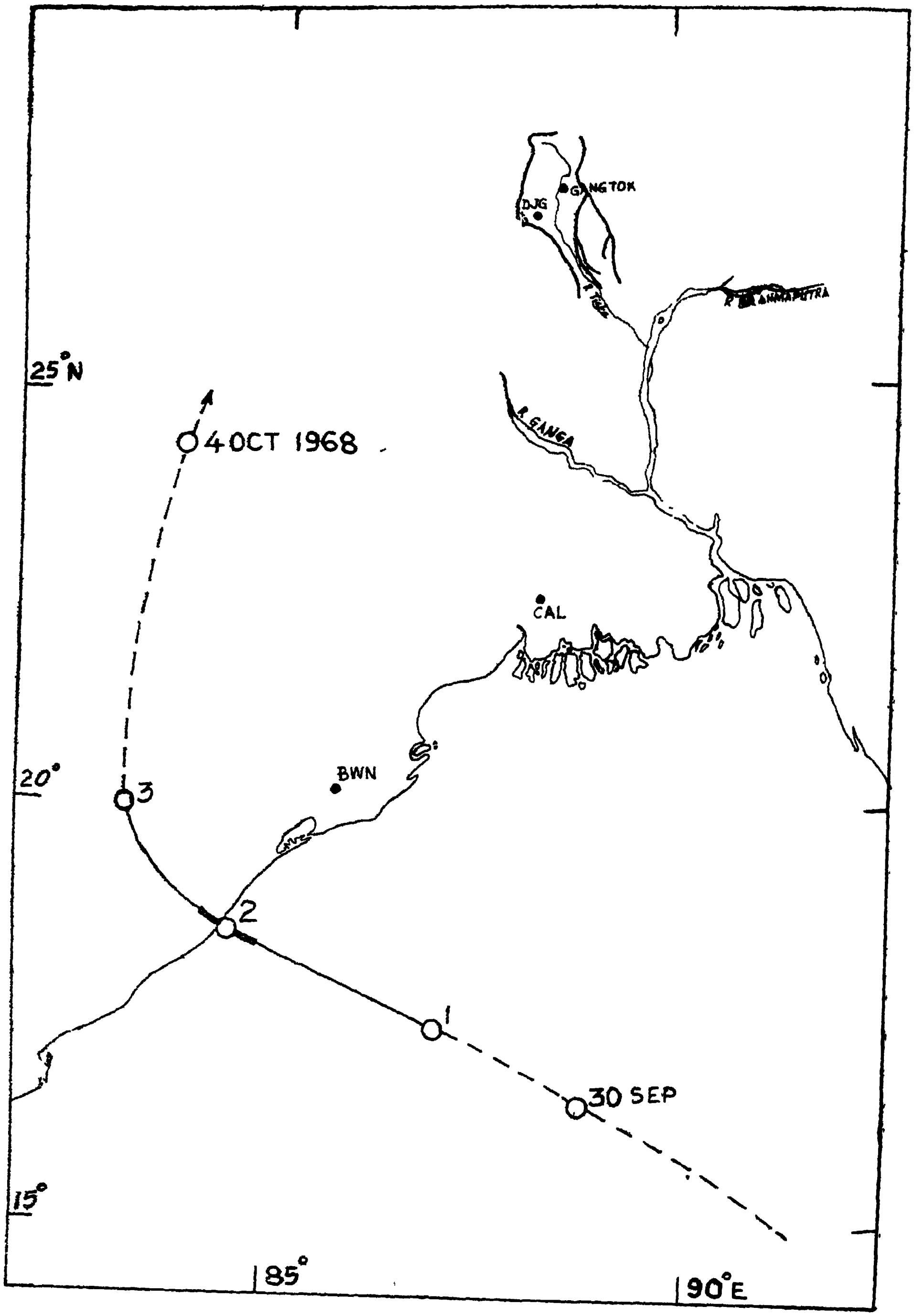


Figure 12 1 Bay of Bengal Storm/Depression and Catchment of Tista

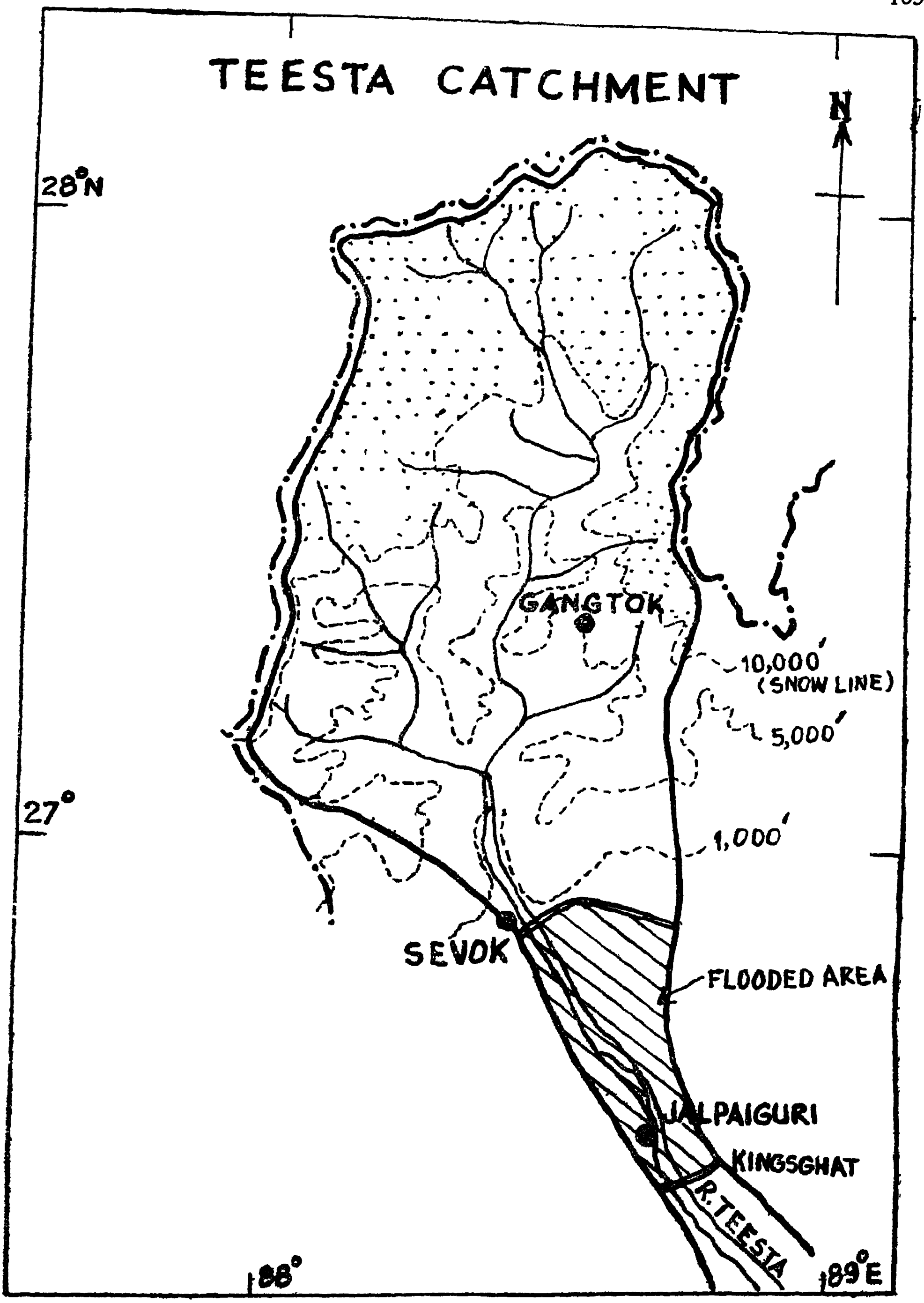

TEESTA CATCHMENT
N
28°N
27°
88°
89°E
GANGTOK
10,000′
(SNOW LINE)
5,000′
1,000′
SEVOK
FLOODED AREA
JALPAIGURI
KINGSGHAT
R. TEESTA

Figure 12.2

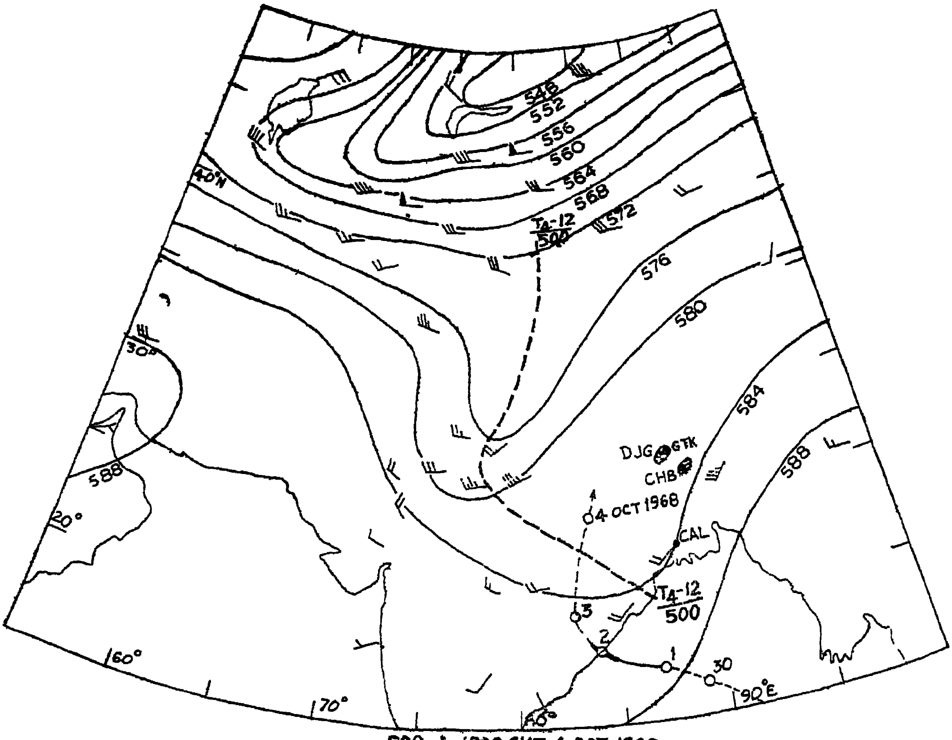


Figure 12.3

this period, as already stated above, the cyclonic system from the Bay of Bengal had completely degnerated into a diffuse low pressure area but the moisture brought in over North Bengal by the Tropical Bay of Bengal system was persisting in the lower troposphere.

The attention of the reader is invited at this stage to the 500 and 300 mb charts at 12 GMT on 4th October vide Figures 12.3 and 12 4. The area of phenomenally heavy rainfall is also shown on the same diagrams. The 500 mb chart of 4th evening (Figure 12.3) leaves no doubt that the contour patterns at that level was highly diffluent and was therefore characterised by pronounced high level divergence (Ramaswamy 1956). At the 300 mb level, and higher levels on 4th evening vide Figure 12.4 there would have been pronounced straight flow with winds increasing in speed downstream and probably reaching jet intensity. Consequently, there would have been pronounced divergence at the right entrance to the jet axis which also lies over the Tista catchment. Consequent on the above conditions, there would have been pronounced up-draught of the monsoon air already injected over the Tista catchment near the surface by the dissipating Bay of Bengal storm.

In emphasizing so much on high-level divergence it is not our intention to underestimate the importance of lower tropospheric convergence in association with

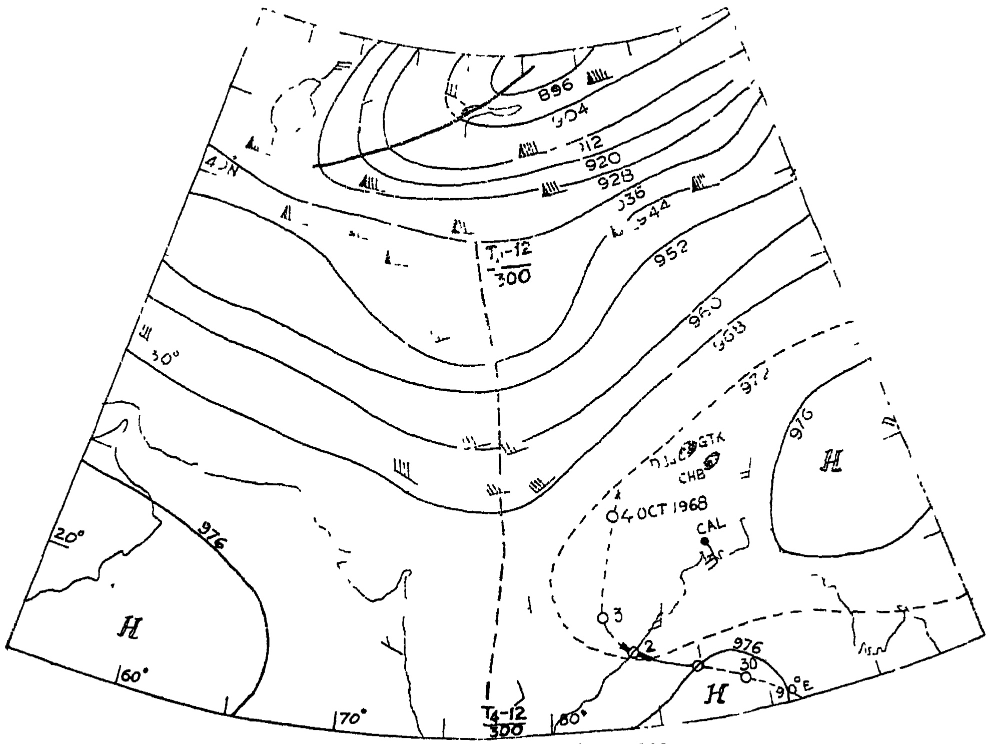


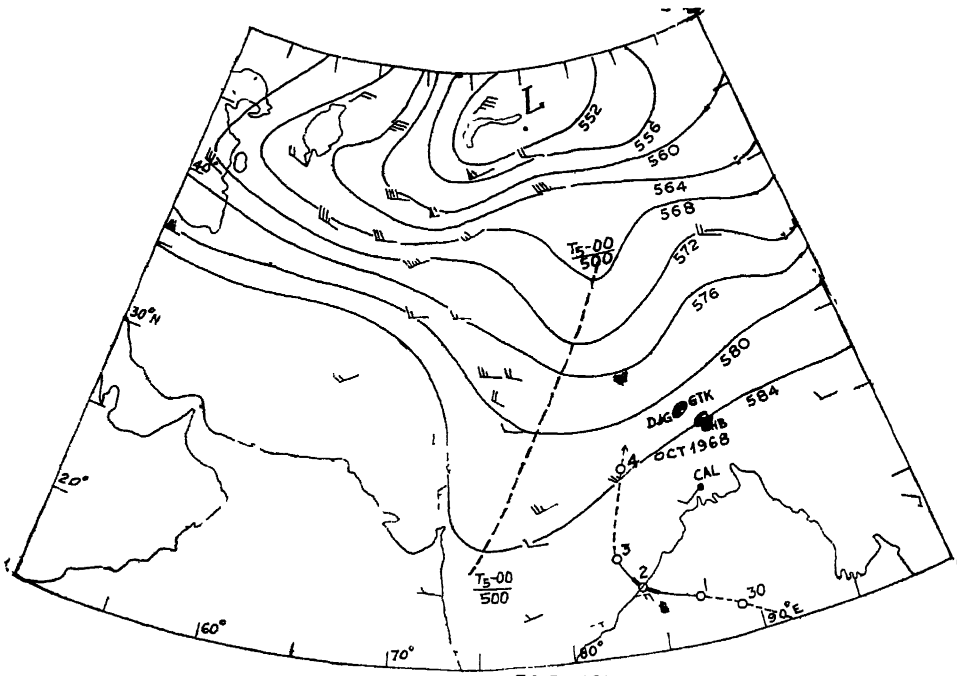
Figure 12.4

the Bay of Bengal system. What we wish to stress is that the *order of magnitude of the rainfall became very much higher after 3rd October on account of the superposition of the middle-latitude system which had come into the picture independently at the higher levels.*

Apart from the above, orography and meso-scale factors especially in the hilly tracks would have also contributed in the lower troposphere to heavy rainfall. For instances, it is likely that the amount of 100 cms of rainfall reported by Pedong on the morning of 3 October (Table 12.1) and another 70 cms on the morning of 4 October were due to the meso-scale factors (see also our discussions in section 5 on satellite pictures).

4. Rainfall and Isohyetal Analysis

Figure 12.7 shows isohyetol pattern (I. Met. D 1969) of the 3-day rain-storm of 3-5 October 1968 over North Bengal which included the Tista catchment, besides other parts of North Bengal. The India Meteorological Department have also stated in their article that the 3-day average depth of precipitation over North Bengal in association with this storm was 441 mm. According to I. Met. D. the 1968 storm had



500 mb, 00 GMT, 5 OCT 1968

Figure 12.5

Table 12 1 *Very heavy rainfall (who leccnitmmetres) over and near the Tista Basin in October 1968.*

Raingauge Station	3	4	5
Pedong*	100	70	
Sankas	76	64	40
Sivok	38	38	
Lgba	32		
Kolimpong	7	26	47
Bagdogra	18	15	35
Jalpaiguri	12	11	
Cooch-Behar		12	29
Kurseong		30	64
Darjeeling		21	29
Mongpoo		32	52
Tista Bridg			29
Musong			29
Rongo		28	
Ressium		28	

*Pedong had 60 cms on 2nd.

AXIS OF TROUGH AT 500&300 mb LEVELS BETWEEN 3 AND 5 OCTOBER 1968

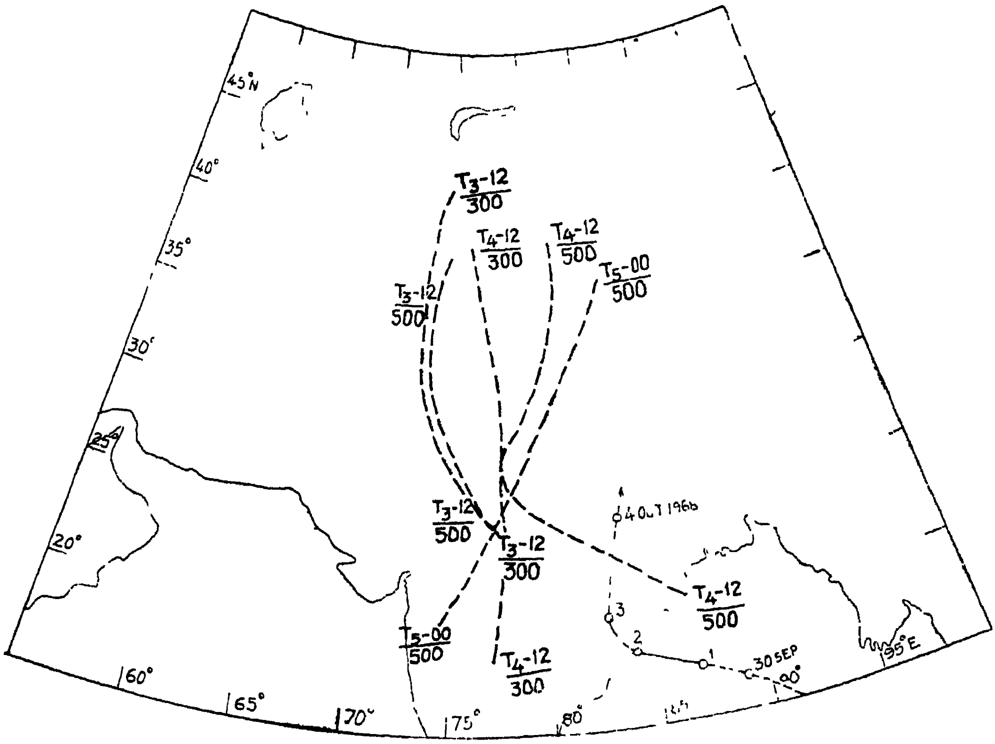


Figure 12.6

contributed a 3-day average of rainfall over North Bengal comparable to the highest 3-day average so far recorded.

Gupta and Abbi (1972) have also pointed out that in association with the heavy rainstorm, the rainfall over the Tista catchment *above* North Bengal region was generally much less in comparison with the rainfall over the Tista catchment in North Bengal.

Table 12.1 shows noteworthy instances of very heavy rainfall over and near the Tista Basin in October 1968.

Table 12.2 shows the average rain-depths in Tista catchment between 1902 and 1968. It has been reproduced from the paper by Gupta and Abbi (1972) as it is an instructive collection of rainfall data relating to the Tista catchment.

5. Satellite Picture of the Cyclonic Systems (Between 30th September and 4th October 1968)

There are brief references to Essa-6 Satellite pictures in the I. Met. D. publication entitled "India Weather Review Annual Summary part C, 1978". This publication does not however contain photographs of the actual satellite pictures. The following

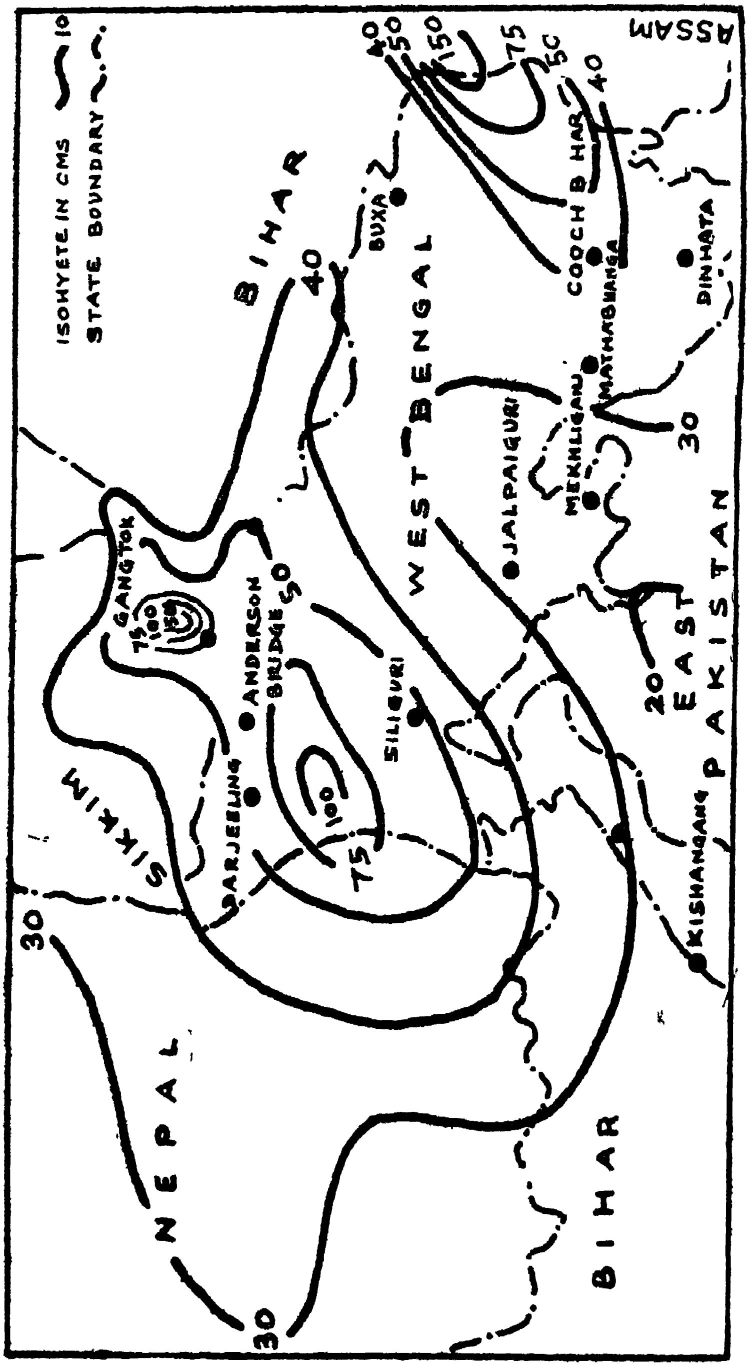

ISOHYETE IN CMS
STATE BOUNDARY
ASSAM
BIHAR
WEST BENGAL
EAST PAKISTAN
NEPAL
SIKKIM
BIHAR
GANGTOK
ANDERSON BRIDGE
DARJEELING
SILIGURI
BUXA
COOCH BEHAR
MATHABHANGA
DINHATA
JALPAIGURI
MEKHLIGANJ
KISHANGANJ
30
40
50
75
100
150
20

Figure 12 6

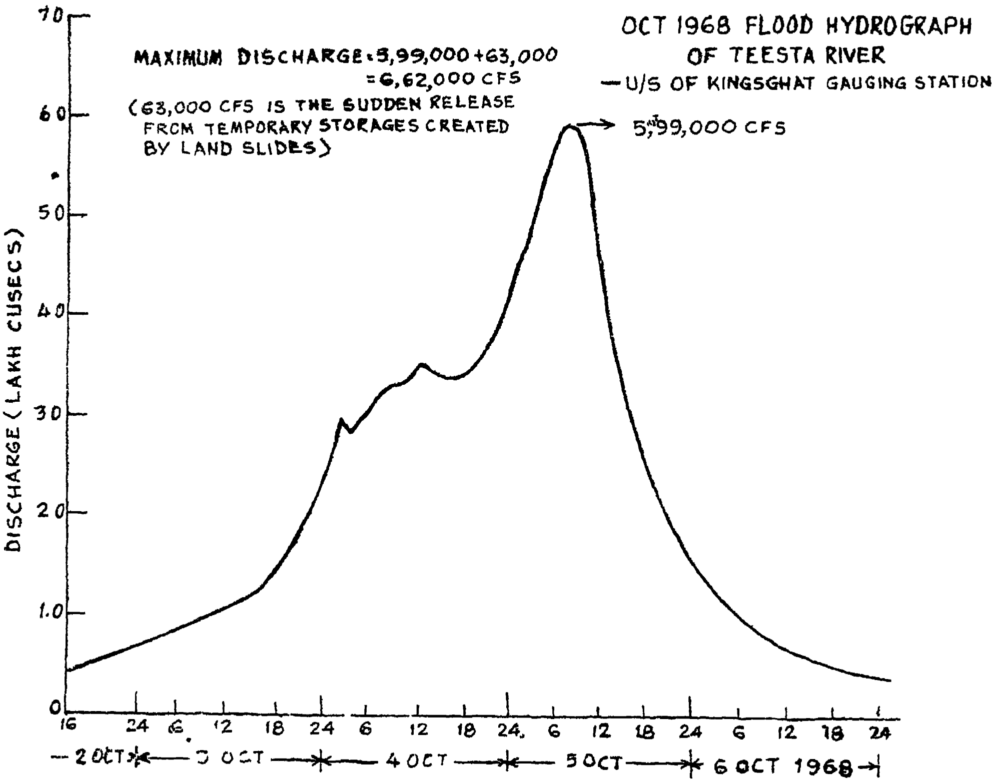


Figure 12 8

are almost verbatim quotations from the above-mentioned publication. While perusing these quotations, the reader is requested to see the track of the "first weather system" in Figure 12.6 in our monograph.

Description of Satellite Pictures

(a) At 0902 IST of 30th September 1968, the satellite picture "showed an active cyclonic circulation near 16°N 89°E with bands in all sectors".

(b) At 0955 IST of 1 October 1968—A "Vortex near 17°N 87°E with overcast Cb and heavy Ci clouds all around".

(c) At 1049 IST 2 October 1968—A "vortex near 18°N 83.5°E. The cyclonic system was at its maximum intensity on 2nd morning. As per Essa-6 satellite pictures of this day, the central overcast area associated with this storm was about 5 degrees in diameter and the storm could be classified as one belonging to stage X category". This gives a maximum wind associated with the storm to be of the order of 70 knots. Using Fletcher's formula, the central pressure works out to be 984 mb. The estimated pressure defect at the centre of the storm was about 25 mb on 2nd morning.

Table 12.2 *Daily Average Rain Depths in Tista Cachment*

Sr. No.	Storm Date(s)	Average Depths of Rainfall (mm) 1st day	2nd day	3rd day
1.	10-11 Aug., 1902	64	139	—
2.	27 Sep., 1902	232	—	—
3.	27-28 Jun, 1903	138	108	—
4.	9-11 Jun., 1909	85	55	129
5-	29 Jun., 1913	160	—	—
6.	17-18 Jul, 1919	90	108	—
7.	1- 2 Sep., 1916	125	86	—
8.	7- 8 Oct., 1917	91	163	—
9.	26 Jun., 1918	160	—	—
10.	11-13 Sep., 1920	147	67	107
11.	10-12 Jul., 1921	69	124	73
12.	28-30 Jun., 1926	94	53	56
13.	3- 3 Jul, 1929	36	67	110
14.	11 Sep., 1929	182	—	—
15.	22-24 Jul., 1931	58	102	59
15.	20-22 Jul., 1940	44	97	165
17.	11-13 Jun., 1950	79	327	199
18.	9 Jul., 1959	183	—	—
19.	27-28 Sep, 1960	77	139	—
20.	17-19 Aug., 1962	95	68	66
21.	3- 5 Oct., 1968	95	170	240

According to the account given in the India Weather Review Annual Summary Part C 1968 which is really a postmortem analysis of the storm after all the coastal observations had been received and scrutinised, the I. Met. D. observatory at Kalingapatnam had recorded a pressure deficiency of 22.4 mb which is not very different from the estimated pressure defect of about 25 mb at the centre of the storm on the basis of the Essa satellite pictures. *Thus we see indirectly, the usefulness of the satellite observations in the analysis and forecasting of Tropical Cyclones in the Bay of Bengal when the conventional observations are not available due to dislocation of telecommunication channels.*

Essa-6 pictures of 3 October and 4 October 1968 have been obtained by the author from U.S.A. films available in the Satellite Meteorology Division of the office of the Director General of Meteorology New Delhi. The picture of 3 October at 1400 IST (Figure 12.9) shows the picture of the first cyclonic system when it lay with its centre near Titilagarh (20°18′N 83°18′E) in Orissa.

The flow of moist air into West Bengal and Bihar plains was vigorous on this day as judged from the upper winds at 1.5 Km asl. They were southerly 45 knots

on the afternoon of 3rd over Calcutta but the *flow weakened by the afternoon of 4th and thereafter also*. This was confirmed by the other upper wind observations over Northeast India.

Besides the above, there was another area of Cb overcast between 85° E and 95°E. This was presumably associated with the upper level trough in the westerlies.

There was a dramatic change in the satellite picture on the afternoon of the 4th (Figure 12.10). With the rapid weakening of the Bay of Bengal system, there was only one area of overcast with Cb clouds extending from 20°N85°E extending initially northwards and later north-northeastwards upto 35°N 95°E. The picture strongly reasembles the satellite picture associated with a moving upper level trough in the westerlies illustrated on page 149 in the W.M.O. Technical Note No. 124. The satellite picrure in Figure 12.10 thus confirms very vividly the conclusions we have drawn in Section 3 on "Large scale synoptic situation". In this connection we would like to draw the special attention of the reader to sub-paragraphs 3.2 4 and 3 2.5.

6. General Conclusions

We thus arrive at the important conclusion that, *contrary to the conclusions drawn by the earlier workers*, the phenomenally heavy rainfall over the Tista catchment was predominantly due to high-level divergence and only partially due to lower tropospheric convergence, orography, meso-scale factors etc. In other words, we had on the present occasion, a typical case of vigorous interaction between middle and low latitude systems. We are however unable at this stage to give quantitative estimates of the contribution made by the various factors.

For the sake of completeness, the author would like to add that the deluge might also have been partly associated with non-meteorological causes discussed in the UNESCO circular referred to in the earlier part of this paper.

7. Flood Damage

Flood Control and Irrigation Works

Breaches had occurred in embankments varying from 35 m to 201 m (115 feet to 660 feet) at a number of places along the river course. Two solid spurs constructed in 1967 were completely washed away and 30 of the permeable spurs were heavily damaged. Several irrigation schemes were also badly damaged.

Damages to Railway Structure

The floods caused extensive damage to the railway lines, railway bridges, approach and guide bunds and other engineering structures and listed below :

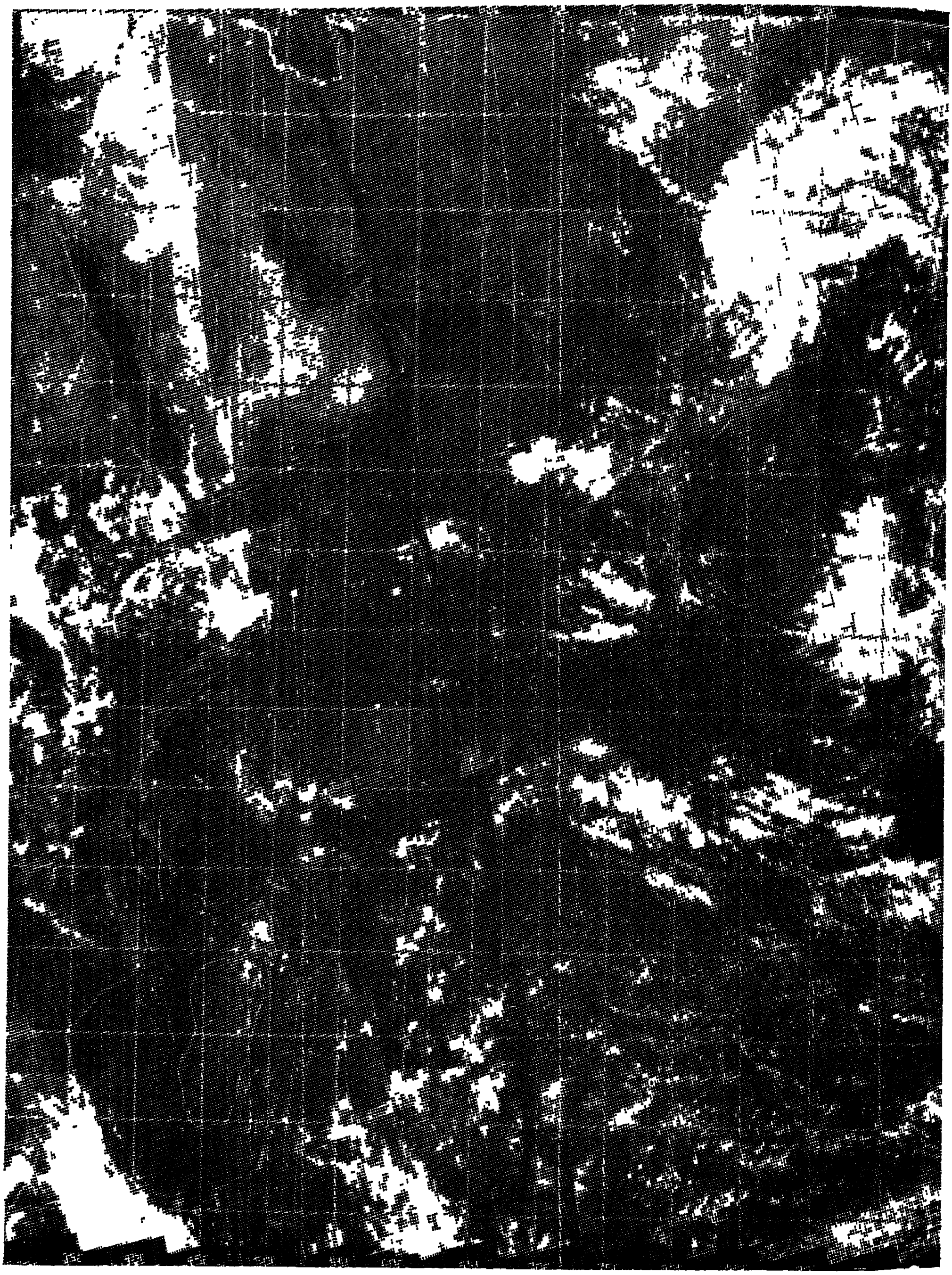


Figure 12.9

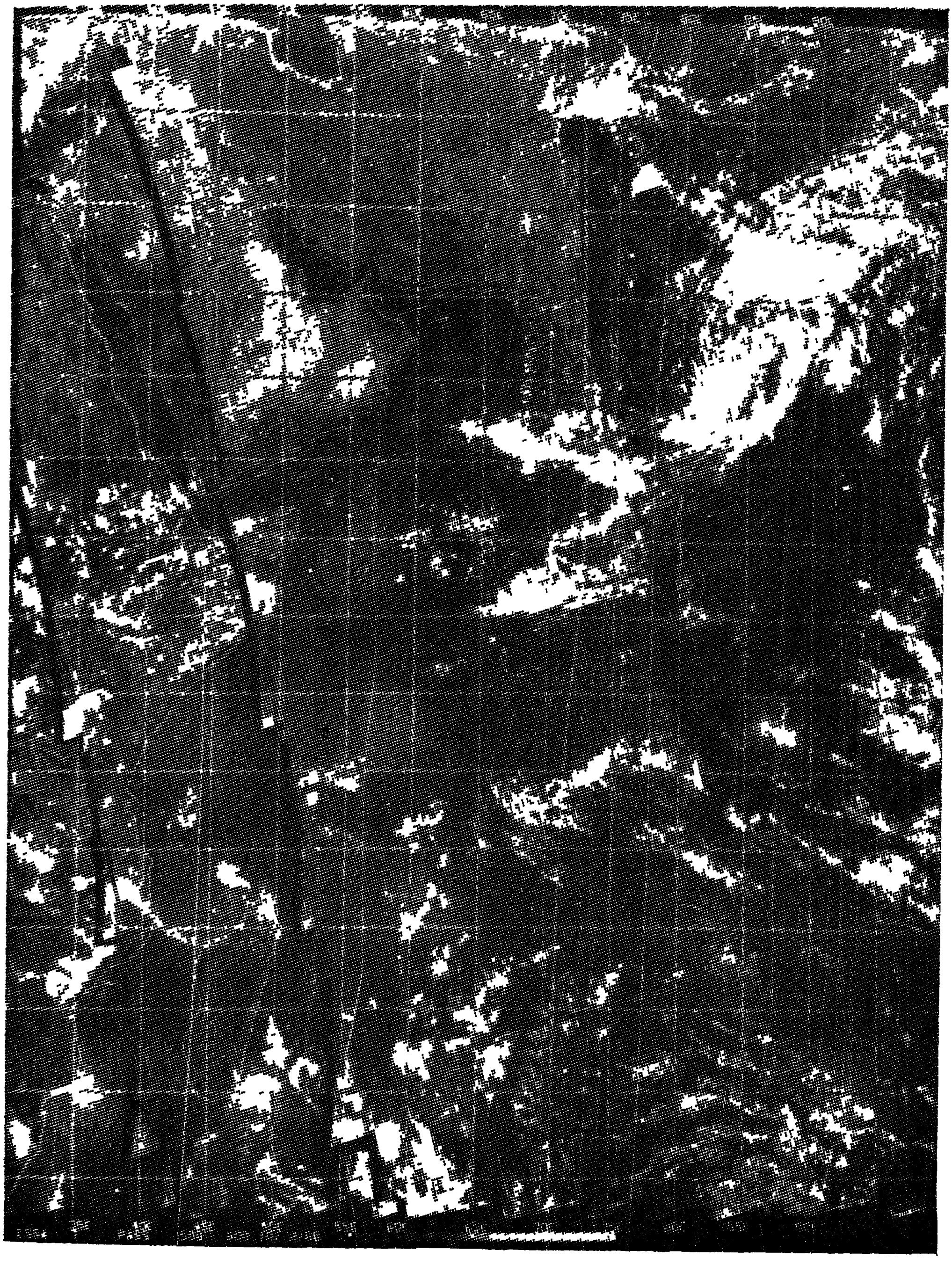


Figure 12 10

Sl. No	Item	No. of works affected
1.	No. of bridges washed away	3
2.	No. of bridges damaged	6
3.	No. of bridges not affected but approaches washed away	23
4.	No. of places where railway sections were breached/washed away and total length	56 15700 m (51,500 ft)
5.	No of places where the railway lines were overtopped and total length	6 20,420 m (67,000 ft)

The Total direct damage to the engineering structures of the railway had been estimated about Rs 4 crores.

Note: *A verbatim extract from Unesco Circulation SC/IHD/IV/25—AnnexIII Appendix III entitled "Report on causes of flood damages and protective measures in the Tista river".

Damages to Road Structures

In all about 32 Km (20 miles) of the highways, 37 bridges on the national highways and 261 bridges and culverts on other roads were damaged by the floods. The Anderson Bridge on the National Highway was completely washed away

Other Damages

Engineering structures of the hydro-electric projects on the Jaldhaka, the Bijanbari, the little Rangit and the Fazi have suffered heavy damages due to floods and land slides.

Due to heavy on-rush of water and the impact of the floating trees brought down from the numerous land slides in the upper catchment, the Anderson Bridge at Tista Bazzar was washed away.

A number of villages and towns in the districts of Darjeeling and Jalpaiguri were affected by the floods. About 2700 human lives and 59300 cattle were lost during the floods. The total assessed cost of flood damage was about 26 crores of rupees.

CASE No. 13

CATASTROPHIC FLOODS IN THE NARMADA IN SEPTEMBER, 1970

1. Hydrological Information

These floods have not been included by UNESCO in their catalogue (1976) presumably because the Central Water and Power Commission (C.W. & P.C) of Government of India had not included it in their list communicated to the Unesco. It should however be mentioned that the September 1970 floods in the Narmada had registered record peak-discharge and record flood-level at Garudeshwar (Abbi et. al 1972, Rao, K. L., 1975 and Dhar et al. 1975).

The following hydrological data have been collected by the writer from the contributions of the above-mentioned authors.

Table 13.1

Gauging Staion : Garudeshwar (21° 45′N, 73° 55′ E)

Qmax M^3/sec.	Date	Maximum recorded level at gauging site (metres)	Danger level (metres)	Difference between highest flood-level and danger-level (metres)
59000	6 9 70	41 65	24.00	17 65

2. Large Scale Synoptic Situation

The floods were directly associated with a land depression which developed over Gangetic West Bengal and adjoining Bihar Plateau on 2nd September 1970. The land depression became deep by the morning of 3 September with its centre about 50 km east of Ranchi over the Bihar plateau. Moving westwards with a slight southerly component after 4 September, *it travelled almost parallel to the orientation of the Narmada basin upto the evening of 6 September*. The pressure deficiency at the centre of the cyclonic system between 3rd and 7th was about 8 to 10 mb and the cyclonic circulation extended vertically upto 9.0 km asl. Subsequently the depression moved northwards and lay over south-west Rajasthan on 8th. There after, moving southwestwards, it emerged into the North Arabian Sea on 9th evening. The subsequent history of this depression is of no special interest to us from the point of view of the Narmada floods. Hence we will not go into it further here. The track* of the depression may be seen in Fig. 13.1.

The antecedent precipitation was also somewhat favourable for the floods They were associated with a mid-troposphere disturbance (Miller et al 1968, Mak 1975, Ramaswamy and Subba Rao 1978) over North Gujarat and adjoining Rajasthan on 31 August and 1 September 1970. The rainfall produced by this disturbance was however only moderate

Note : The author of this monograph has taken the tracks exactly as shown in the important and authoritative I. Met. D, publication entitled "Atlas of tracks of storms and depressions in the Bay of Bengal and the Arabian Sea". The tracks as shown by Abbi et al (1972) are somewhat different.

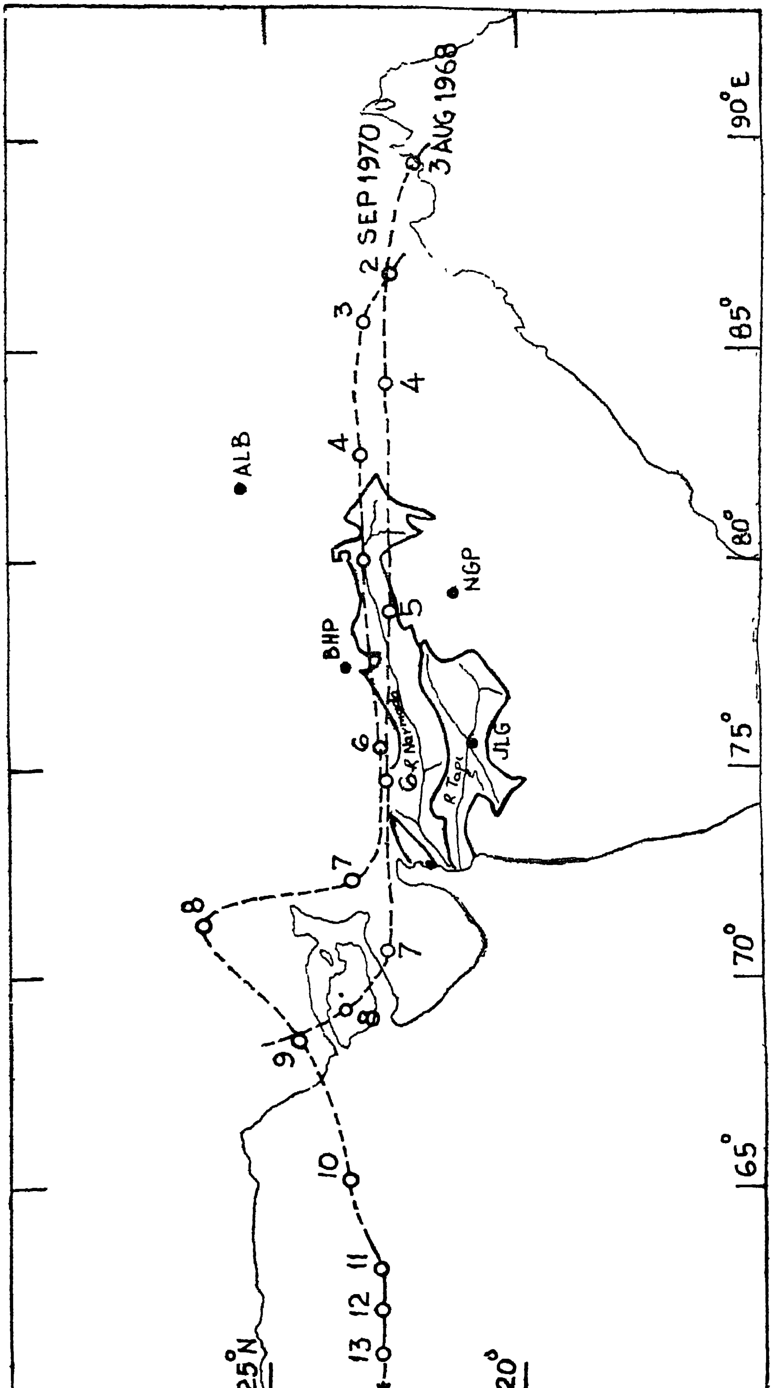


Figure 13.1 Tapi & Narmada Basins

3. Mechanism of Steering of the Depression in September, 1970

Figures 13 2 and 13 3 show the 200 mb contour patterns over and to the north of India at 00 GMT on 3rd and 7th September, 1970. The 200 mb level lay just above the field of the depression. The positions of the centre of the depression at sea-level on 2nd, 3rd and 4th September are shown on the chart for 3rd September vide Figure 13.2. Similarly, the centres of the depression at sea level on 6,7 and 8 September 1970 are shown on the 200 mb chart for 7 September vide Figure 13.3 It will be seen that the flow patterns are reasonably consistent with the direction of movement of the depression. Consequently they provide a useful quasiempirical tool to the forecaster for indicating the probable movement of depressions and storms over the Indian subcontinent (see also Ramaswamy 1972).

4. Rainfall Analysis

A number of stations in and around the Narmada catchment recorded heavy to very heavy rainfall in association with the depression The chief amounts of rainfall are indicated in Table 13.2.

Table 13.2

Station	*Rainfall* 5th	*amount in* 6th	*milimetres* 7th
Valia	168	246	
Mangrol		207	265
Barwani	82	257	
Khargone	72	248	
Maheshwar	150	240	
Thikri	65	233	
Baroda		65	204
Ahmedabad		106	66
Dediapada		215	159

5. Isohyetal Analysis

The isohyetal pattern for the rainstorms over the Narmada basin during the period 5-7 September 1970 has been published by Abbi et al (1972). It is shown in Figure 13.4. For purpose of comparison, the isohyetal pattern for the rainstorm of 4 to 6 August 1968 (Pant et al 1970) is also shown in Figure 13.5. The Depth-Area-Duration

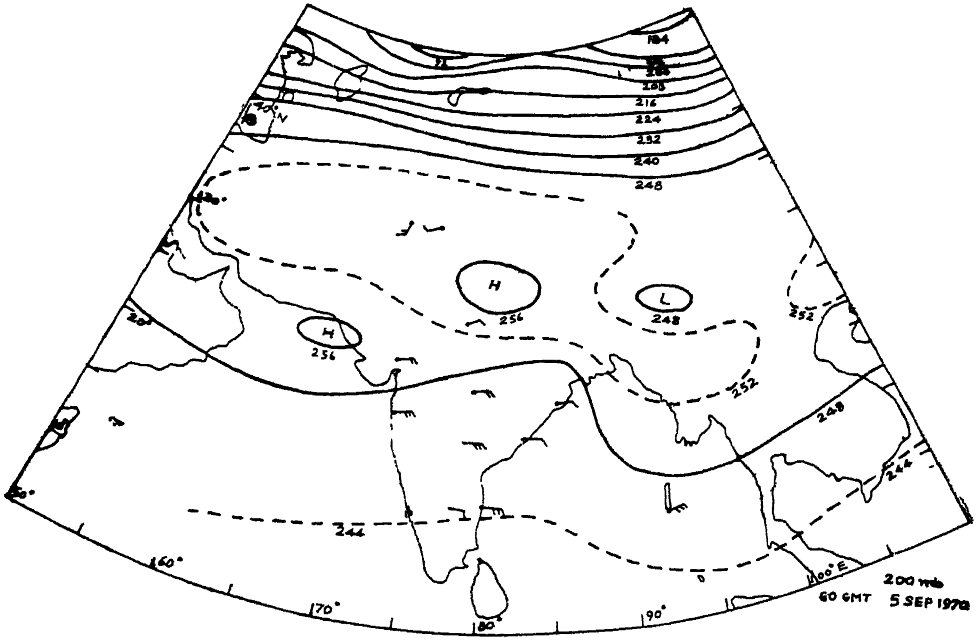


Figure 13 2

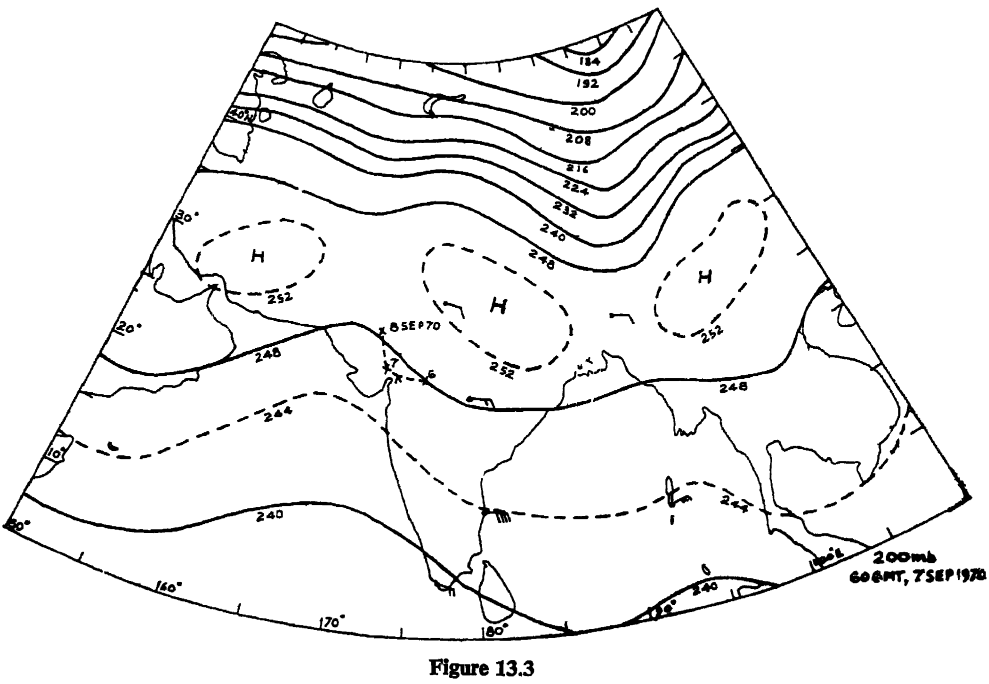


Figure 13.3

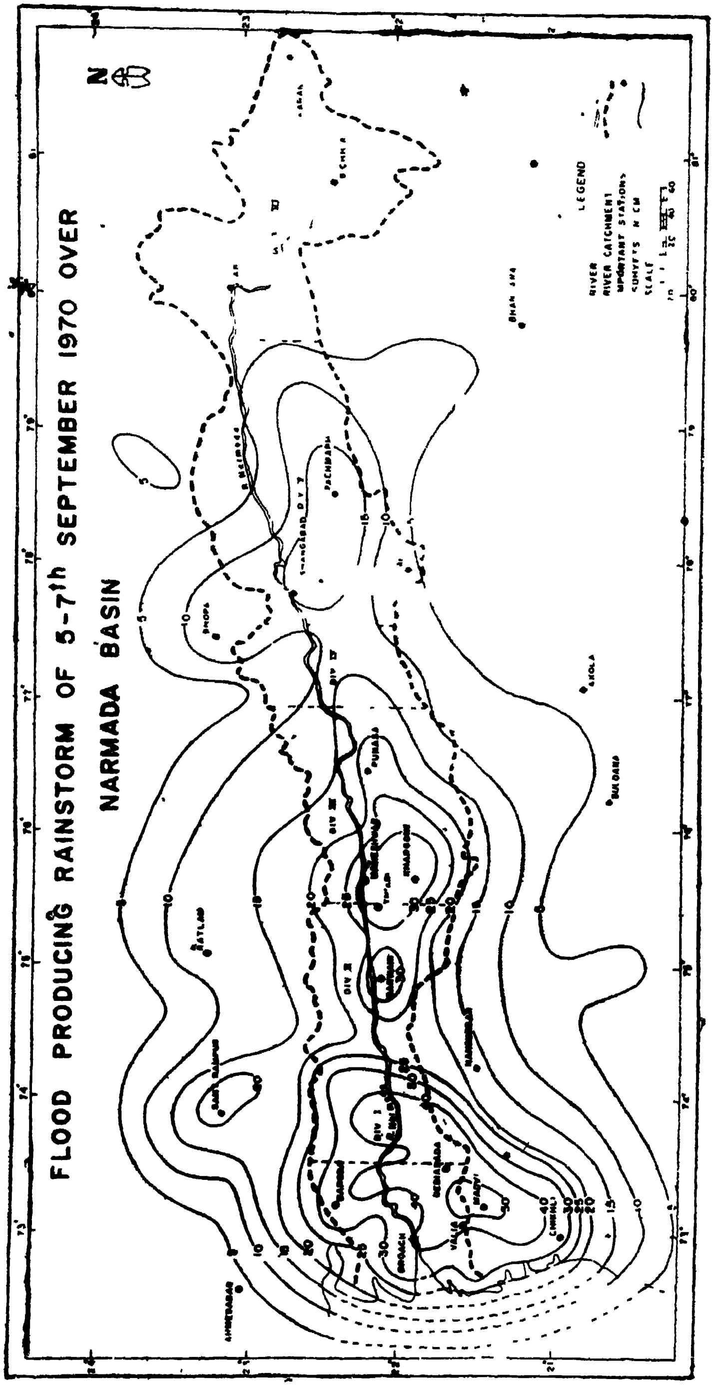

FLOOD PRODUCING RAINSTORM OF 5-7th SEPTEMBER 1970 OVER
NARMADA BASIN
LEGEND

Figure 13.4

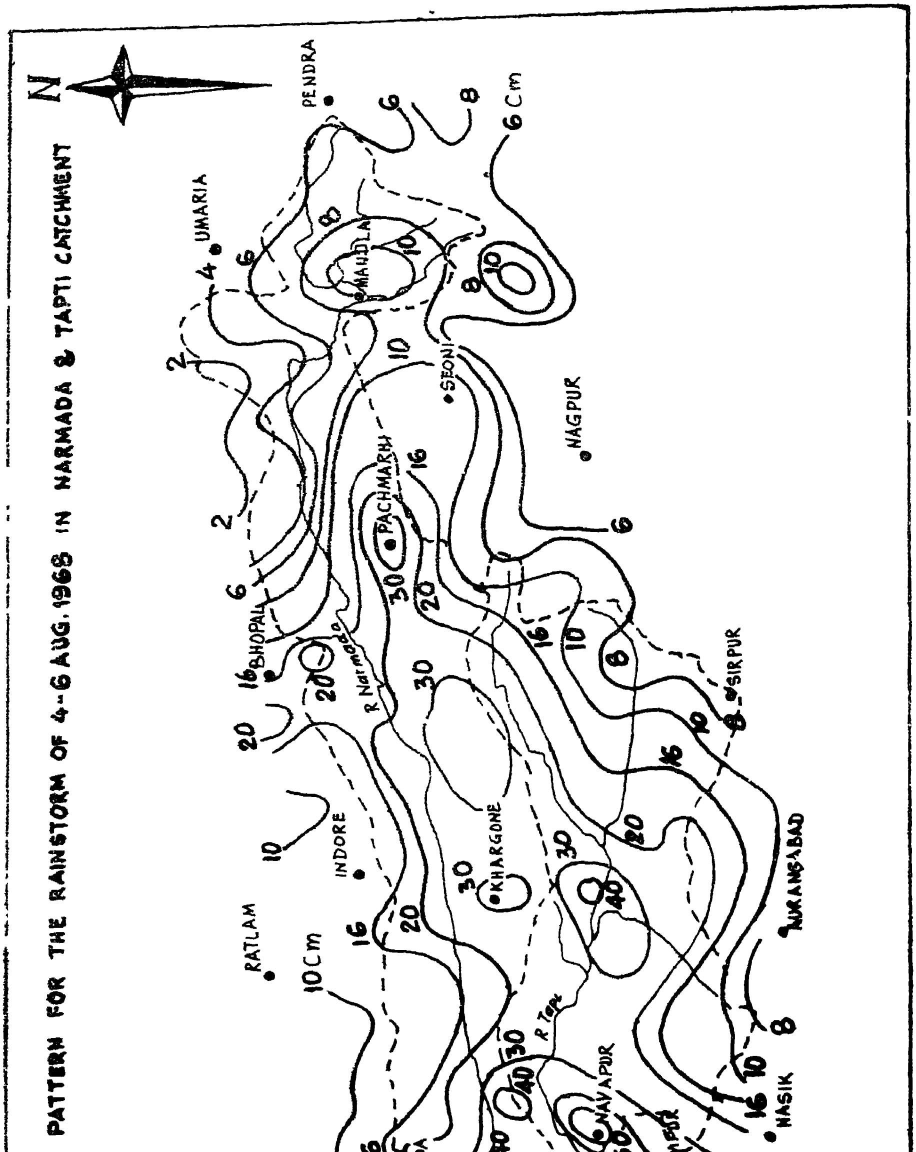

ISOHYETAL PATTERN FOR THE RAINSTORM OF 4-6 AUG. 1968 IN NARMADA & TAPTI CATCHMENT
N
PENDRA
UMARIA
MANDLA
SEONI
NAGPUR
PACHMARHI
BHOPAL
R Narmada
SIRPUR
INDORE
KHARGONE
RATLAM
KHANSABAD
R Tapi
NAVAPUR
NASIK
DHARAMPUR
BARODA
BROACH
SURAT
6 Cm
10 Cm

Figure 13 5

Curve for the storms 5-7 September 1970 and the observed flood hydrograph at Garudeshwar Gauging site during the period 1-10 September 1970 may be seen in Figures 13.6 and 13.7 respectively.

A comparison of the isohyetal patterns for the period 4-6 August 1968, a series of rainstorms were spread over the entire length of the catchment whereas for the period 5-7 September, 1970 the rainstorms were more concentrated in the western half of the Basin (see also Abbi et al 1972).

The isohyetal average contributed by the rainstorms of 4-6 August 1968 (Pant et al 1970; Abbi et al 1970) and of 5-7 September 1970 (Abbi et al 1972) are given in Table 13 3 below :

Table 13.3

Storm Period	Maximum 1—day (mm)	Maximum 2—day (mm)	Maximum 3—day (mm)
4—6 August 1968	76 (5th Aug)	145 (5-6 Aug)	174 (4-6 Aug.)
5—7 September 1970	87 (6th Sept.)	127 (5-6 Sept.)	160 (5-7 Sept.)

It will be seen from the above that 1-day isohyetal depth of precipitation recorded on 6 September 1970 was more than that recorded on 5 August 1968. However, in the case of the averages for rainstorms of 2 and 3-day durations, the values in September 1970 are less than those in August 1968. We shall attempt to explain this in a later section.

6. Comparative Theremodynamic Analysis of the Flood Situations in September 1970 and August 1968

The daily tephigrams for the period 5-7 September 1970 and 4-6 August 1968 were prepared by us and the mixing ratios at and below 800 mb level were compared. The mixing ratios at any specific level at a particular hour of observation did not significantly differ during the two spells. This implies that any differences in the rainstorms during the two spells were due to differences in the dynamical processes involved and not due to any large differences in the moisture content of the air.

7. Comparative Analysis of the Upper Wind Flow Patterns at 1.5 km in August 1968 and September 1970 Spells over the Narmada Basin

The 1.5 km level is accepted by Indian synoptic meteorologists as most representative of the *lower tropospheric convergence* and moisture-content. In studying the 1.5 km level charts shown in Figure 13.8 (a), (b), (c) and (d) we should also remember thatwse are studying these from the *prognostic* point of view. In other words, each day' chart should be compared with the subsequent 24-hour rainfall. Now we note that

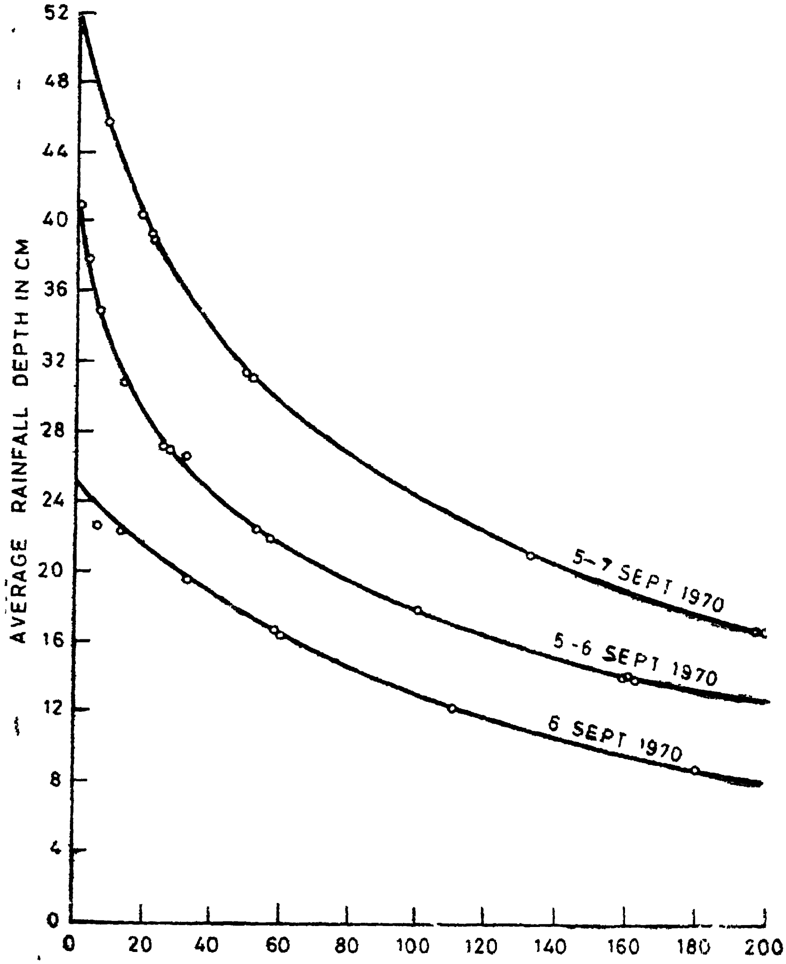


Figure 13.6 Depth Area Duration Curves for the Storm of 5th-7th September 1970

the convergence at the 1.5 km level on 5 September 1970 was much more marked in the lower reaches of the Narmada than on 4 August 1968. Note the dead northerly 25 knot winds over Ahmedabad and 25 NNE winds over Udaipur on 5th September. Note also the 50 knot westerly winds over Poona at the same synoptic hour. Consequent on the above, cyclonic vorticity and wind-convergence in very high in the lower-most reaches of the Narmada on 5 September 1970. In contrast, the winds over the same area on 4 August 1968 are lighter. The area of convergence is also diffuse. Subsequently, however, the conditions became reversed. The convergence

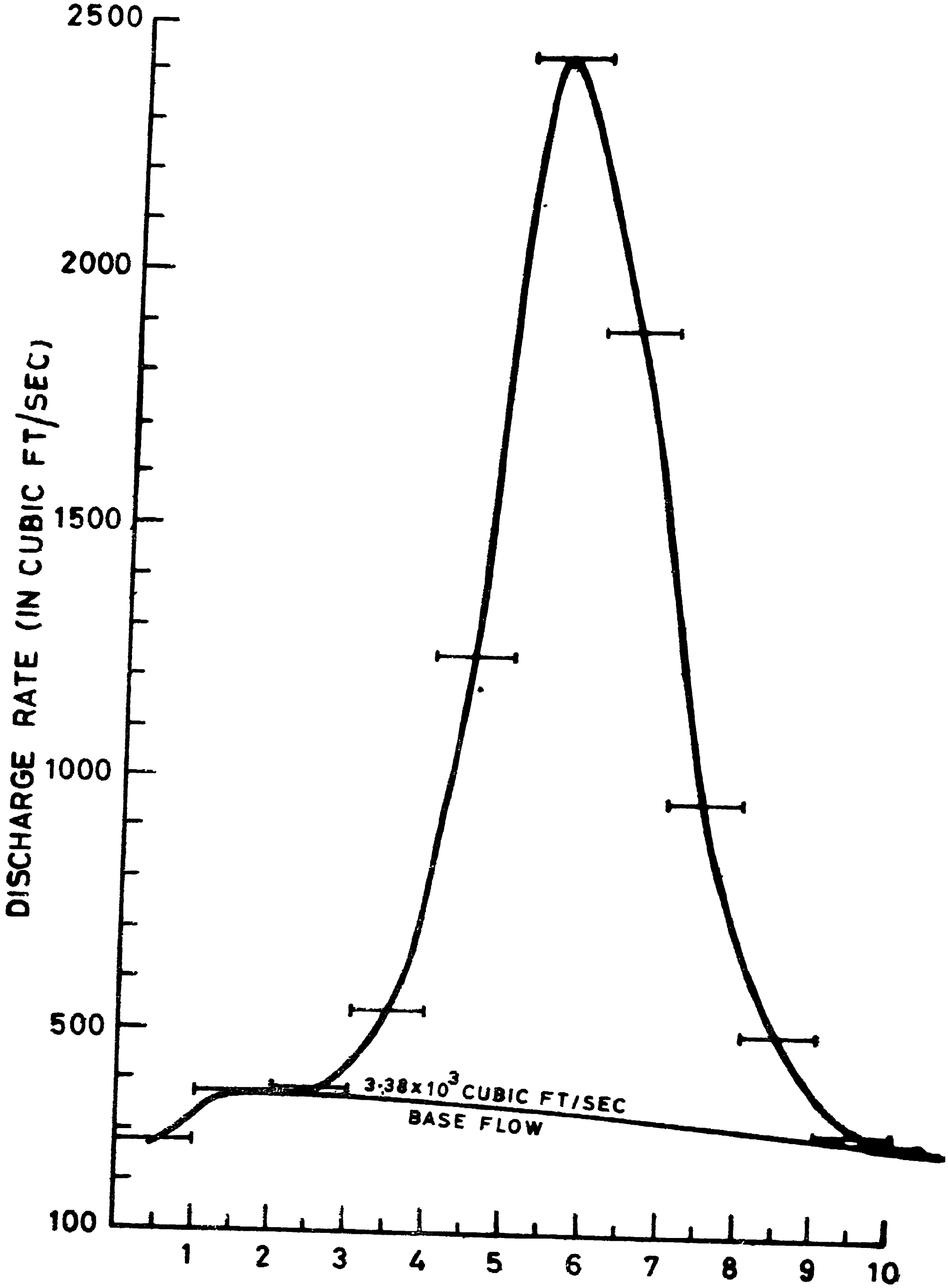


Figure 13.7 Observed Flood Hydrograph of Narmada 1st to 10th September 1970 at Gardeshwar Gauging Site

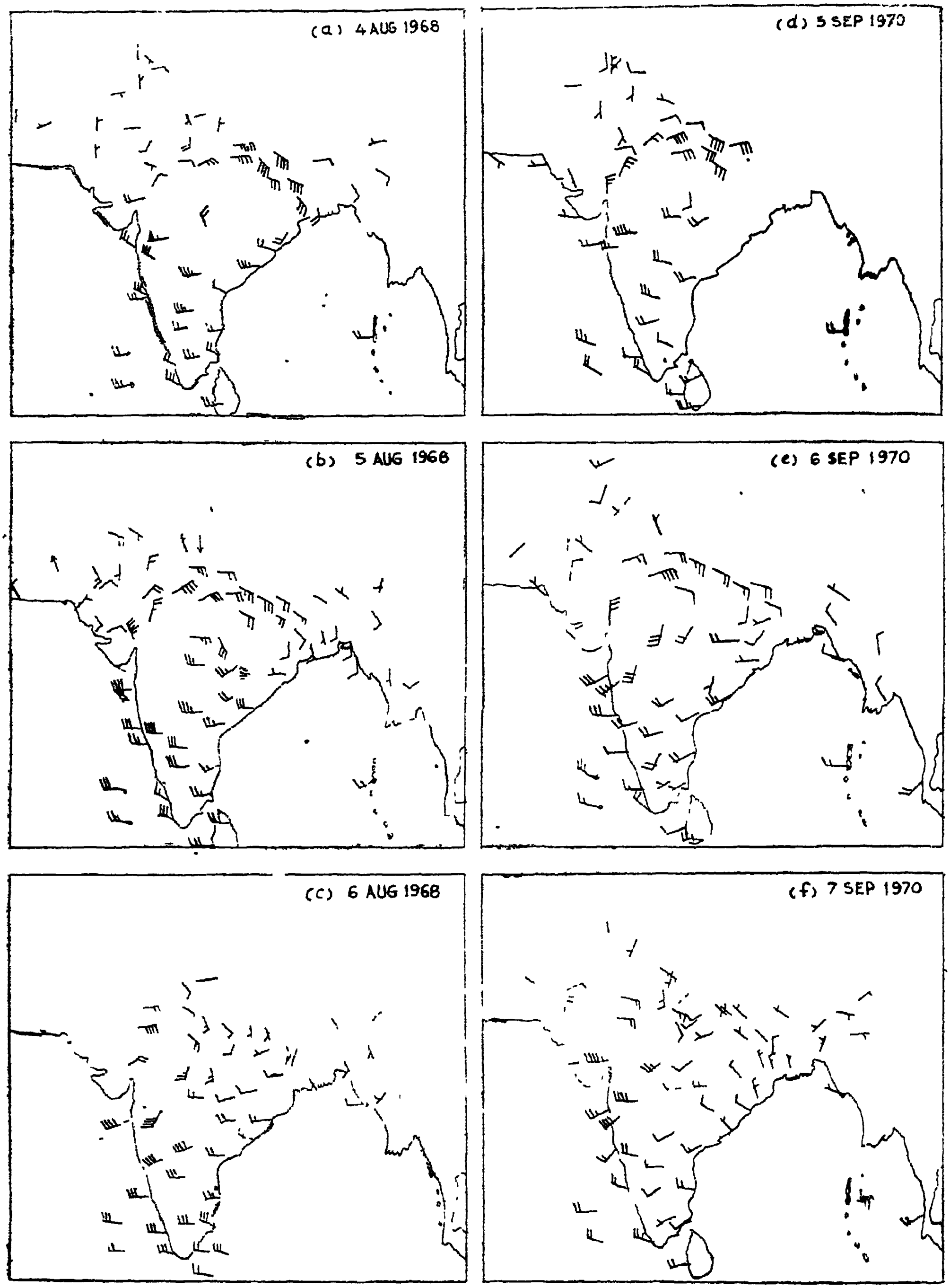

(a) 4 AUG 1968
(d) 5 SEP 1970
(b) 5 AUG 1968
(e) 6 SEP 1970
(c) 6 AUG 1968
(f) 7 SEP 1970

Figure 13.8

in the lower reaches was more on 5 and 6 August 1968 than on 6 and 7 September 1970.

8. General Conclusions

Under these circumstances and on the assumption that other conditions were the same, we come to the conclusion that the September 1970 system should have caused less severe rainstorms over the Narmada catchment than the August 1968 spell. In other words, the floods in August 1968 were a greater catastrophe than the floods in September 1970. The only point in the September 1970 spell is that the discharge rate at Garudeshwar was higher than in the August 1968 spell. And this can be explained by the fact that the rainstorms occurred nearer to the Garudeshwar discharge site than those in August 1968 spell *which were spread out over the entire catchment.* The fact that the storm-centre in September 1970 was closer to the Garudeshwar discharge site has also been pointed out earlier by Abbi et al (1972).

9. Flood Damage

According to Press Reports, the flooded Narmada and Tapi inundated many parts of Southwest Madhya Pradesh and Broach and Surat Districts of Gujarat. Parts of Mandla, Hoshangabad and Harda towns, were also submerged by the Narmada. The floods in Gujarat State took a heavy toll of human lives and caused very heavy damage to crops and other property. In Broach district some 300 to 400 persons were reported to have been washed away in Tarsali and Titodra villages. Abbi et al. (1972) have stated that the worst affected regions were the districts of Baroda (now known as Vadodhara) and Broach (now known as Bharuchi) where according to the reports received by them the damage had amounted to several crores of rupees.

CASE No. 14

CATASTROPHIC FLOODS IN TAMIL NADU IN DECEMBER 1972

1. Introduction

This case was associated with a cyclonic storm of severe intensity which struck the coast of Tamil Nadu just to the north of Cuddalore and caused destructive winds, very heavy rain and floods. *The destruction caused by heavy rain and floods was far more than that caused by the high winds.* We have therfore included this case in our monograph.

2. Hydrological Data

Very little hydrological data in the sense in which this term has been used in this

monograph was available in the present case. The only information which could be included under this catagory was that the Neyveli Lignite Mines were flooded by 45 feet of water and that the flood-level in the Bhavani (in Tamil Nadu) was highest since the 1924 flood in the Cauvery (Case No. 1).

3. Large-Scale Synoptic Situation

In view of the synoptic importance of this case, we would very briefly describe the sequence of development associated with this cyclone.

Figure 14.1 shows the sea-level isobars at 0300 GMT (0830 hrs IST) on 5th December as published in the Indian Daily Weather Report of I. Met. D. The 24 hours rainfall figures reported at 0300 GMT by the observatories maintained by the India Meteorological Department have also been shown in the same diagram. It will be noted that the heavy rainfall on the coast in the field of the cyclone has mainly occurred in the sector WNW to N of the centre of the cyclone. This is because it is a region of maximum lower tropospheric convergence between the northerlies and northeasterlies on one hand and southerlies and southeasterlies on the other We do not of course know the distribution and amount of heavy rainfall in the areas out in the sea.

The cyclonic system developed a narrow core of hurricane winds around its centre on the 5th December. Subsequently moving westnorthwestwards, the cyclone crossed the Tamil Nadu coast close to and to the north of Cuddalore (11° 46 'N, 79° 46' E) at about 2330 GMT (0500 IST on 6th) on 5 December. It was centred within 50 km westnorthwest of Cuddalore at 0300 GMT on 6th. Later, it weakened into a depression and moving *westsouthwestwards* across the south Peninsula, it emerged into the Arabian Sea off Mysore-Kerala coast on the 8th.

According to the official track approved by the India Meteorological Department (Figure 14.2), the depression ceased to be a depression after 03 GMT of 8th. The arrow shown in Figure 14 2 after 0330 GMT of 8th represents "the point of dissipation" of the eyclonic system.

4. Satellite Pictures of the Severe Cyclone

4.1 T.V. Pictures

The India Meteorological Department (Das, George and Jambunathan 1973) have published ESSA—6 views of the cyclone at about 1030 IST on 4 December 1972 and at about 1015 IST on 6 December 1972 (pictures not reproduced in this monograph). According to these authors, the cyclone was in Stage X, Catagory 2 to 3 and diameter about 3° between 4th and 6th. The maximum wind estimated by the above-mentioned authors from the pictures was about 70 knots which agreed well with the maximum wind of 75 knots reported by Cuddalore.

4.2 Infra-red Pictures

Various stages of the development and dissipation of severe cyclone between 2 and 11 December 1972 are clearly seen in the Infrared satellite Images at 2100 IST

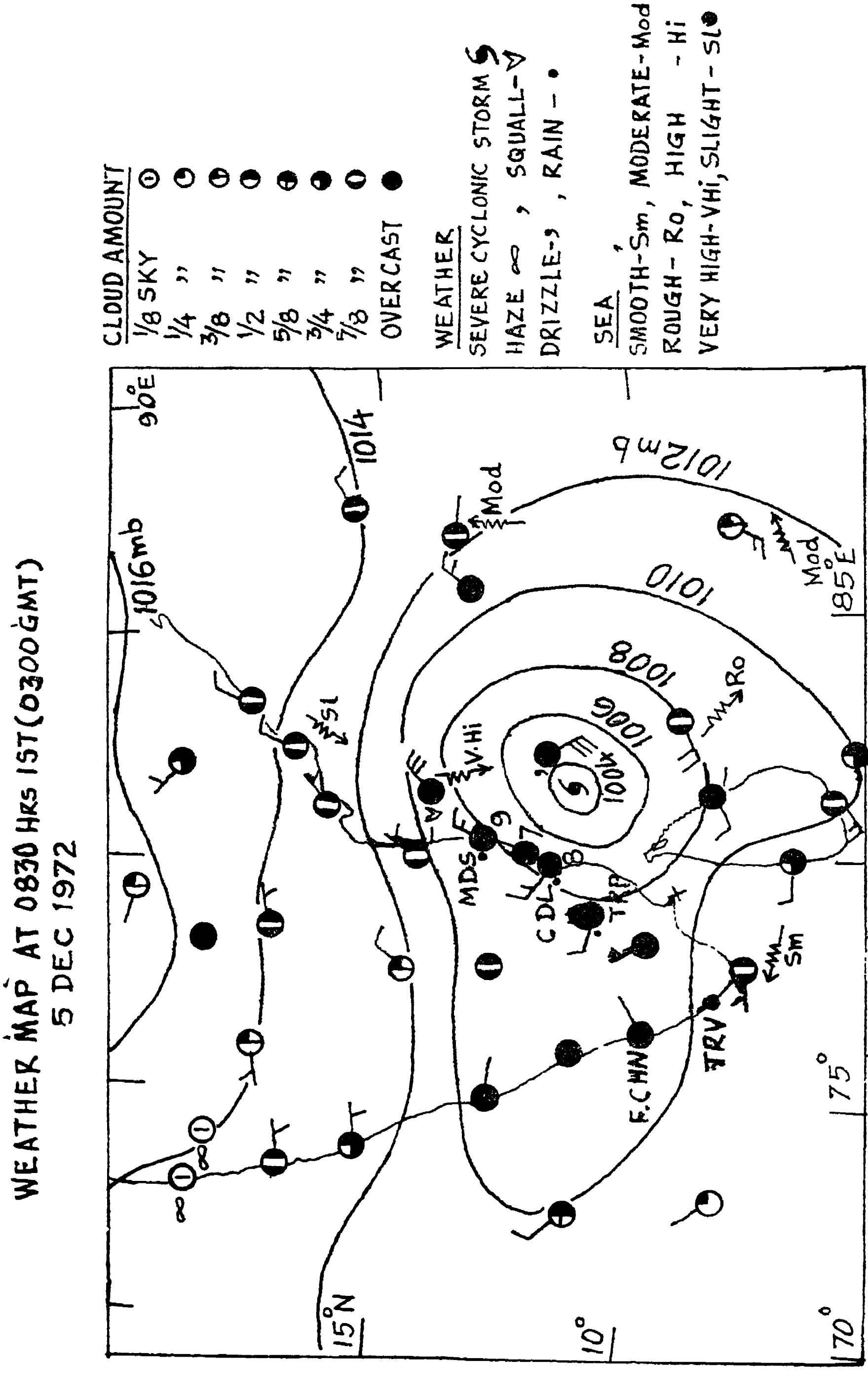
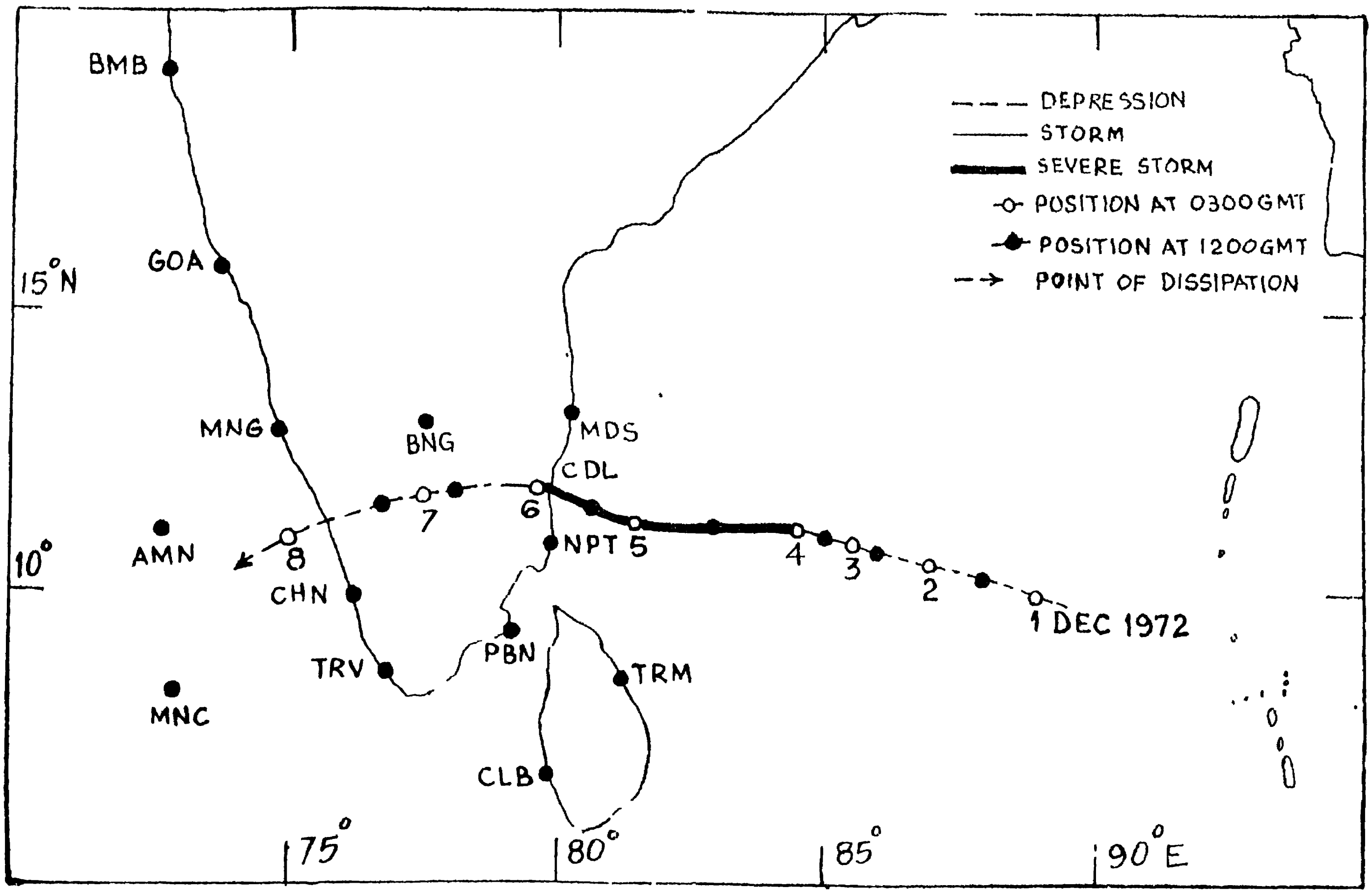


Fig. 14.1 Cuddalore Cyclone



(COURTESY : I MET. D.)

Figure 14.2 Track of Severe Cyclone Which Struck Cuddalore (CDL) on 6 Dec 1972

reproduced by Lengerke (1977) from Hemispherical and Equatorial Mosaics published by the National Oceanic and Atmospheric Administration (NOAA), North Carolina, USA. These picture are very interesting and instructive and have great forecasting value. We are therefore discussing them here in some detail. The pictures for the 2nd and 4th depict the developing stages of the severe cyclone (W.M.O. Tech. Note No. 124, 1973). The pictures for the 5th and 6th show the maximum phase of development. On these two days, the cyclone lay over southwest Bay of Bengal and adjoining parts of Tamil Nadu. The system somewhat weakened as it was moving westwards across the peninsula. *It however intensified again between 8th and 9th* (as seen in the picture for 9th). This regeneration during the course of its entering into the southeast Arabian Sea (on account of the increase in moisture-feed) is in agreement with the synoptic experience of the author of this monograph. We have to bear in mind in this connection that the cyclone developed and moved in the first week of December and is therefore climatologically more comparable with the November cyclonic storms than with those of the mid-or late December storms. The November systems moving in lower latitudes usually move westwards and have a tendency to intensify on their entering the southeast Arabian sea. The number of cyclonic disturbances which developed in the Bay of Bengal and move into the southeast Arbian sea in December is however small. They have also a tendency to acqire a westsouthwesterly component during the course of their movement. The actual movement of such cyclonic storms depends upon the synoptic factors in individual situations. In view of the relatively small number of cases of development of cyclonic storms in December, we cannot attempt any generalisations. All that we would like to stress here is that the infra-red satellite pictures appear more realistic and show more vividly the life-history of the Cuddalore cyclone. *Such infra-red pictures would therefore be of great forecasting value in similar cases in future.*

3. Rainfall Analysis

As stated earlier, the cyclone caused very heavy rainfall over and around Tamil Nadu. The following are some of the rainfall amounts of 13 cms or more in 24 hours ending at 08 hours IST on the dates shown.

Date and month (December)	District	Stations	cms of rainfall in 24 hours ending at 08 hours IST.
6	Soute Arcot	Cuddalore	18
—do—	Chingelput	Kanchipuram	17
—do—	Thanjavur	Mayuram	15
—do—	—do—	Nagapattinam	14
7	—do—	Atirampattinam	22
—do—	Nellore	Kavali	16
—do—	Pondicherry	Pondicherry	16

—do—	Chingelput	Kanchipuram	16
—do—	Thanjavur	Mannargudi	14
—do—	Nellore	Woolapalam	13
8	Kerala State	Kodangllur	22
—do—	Madurai	Gobichettipalayam	18
—do—	Kerala State	Fort Cochin	14
—do—	Thanjavur	Mannargudi	13
9	Coimbatore	Coimbatore City	18
—do—	—do—	Satyamangalam	19
—do—	Madurai	Gobichettipaleyam	18

Besides the above, a large number of stations in the Nilgiris reported 125 mm or more rain in 24 hours between 7th and 9th December.

4. Flood Damage

The Tamil Nadu Government estimated the total damage at 400,000,000 rupees (Forty Crores Rupees) including 70,000,000 rupees worth of standing crops washed away or destroyed by water-logging.

The following quotations from head-lines and news items from the daily newspapers, pertaining to the plains and coastal area prepared by Lengerke (1977). Th ey give a graphic picture of the impact of the cyclone on Tamil Nadu.

5. Extracts from News Paper Reports

Road, rail, traffic distrupted by floods in Tamil Nadu; Madras—Tiruchi rail line totally out off; Bhavani town out of by floods in two rivers; Salem—15,000 Homeless; 10,000 affected in Pondy; 100 villages hit in south Arcot 10,000 families stranded; Car with six washed away—Two villages washed away—Breach of 80 tanks in Pattukottai, 300 feet of anicut washed away; Eight washed away; 3 persons washed away in Bhavani village; Death-toll in south Arcot floods rises to 13.

Neyveli lignite mines flooded by 45 feet . two lorries washed away.. breaches of 1524 major and 1387 minor irrigation tanks road breaches at 1445 places on highways and at 4532 places on other road. 45000 acres of paddy fields under water in Thanjavur District. 248,000 acres of standing crops partly damaged . more than 5000 huts collapsed, 25000 persons homeless 3302 persons rescued from floods in South Arcot...88000 houses in South Arcot District either destroyed or damaged, 35000 in Madras, 16000 in Coimbatore, 10,000 in Tanjore, 7,700 in Salem . in South Arcot all the rivers joined together and flowed through Cuddalore in one stream, submerging on route 1069 of the 2287 villages in that district...flood level of Bhavani highest since 1924 flood...81 persons killed.

CASE No. 15

CATASTROPHIC FLOODS IN THE SONE AND THE GANGA IN AND AROUND THE CITY OF PATNA IN AUGUST 1975

1. Introduction

This is a case of great importance as local topography played an important role in causing disastrous floods in and around the city of Patna.

2. Hydrological Information

The following hydrological data have been extracted from a paper by Dhar and Ghose (1979).

Table 15.1

River	Gauge site and State	Highest level recorded during the flood (m)	Date & Year	Difference between highest flood-level and Danger-level (m)
Ganga	Digha Ghat Patna (Bihar)	52.52	Aug. 1975	2 07
Sone	Chopan (Bihar)	175.61	Aug. 1975	4.61

3. Earlier Literature

Sen, Sarma and Prasad have written two papers about these floods. In their first paper, they have discussed the hydrometeorological as well as the synoptic aspects, the former in much greater detail. Figure 15.1 which is interesting and informative has been reproduced from their first paper. In their second paper, Prasad and Sen Sarma (1978) have discussed the synoptic aspects especially of the persistence of the "Patna depression" near about the same place on 21 and 22 August and the change in the direction of its movement after 22nd In that connection they have discussed about weather system over China and their impact on the Indian synoptic situation.

4. Our Further Study of This Problem

In our opinion, the following points require further consideration :

(a) Was there moderate to heavy rain in the Yamuna or its southern tributaries between Allahabad and Delhi which could have caused a rise in the flood-level in the Ganga and thereby aggravated the flood-situation at Patna ? If not, could the heavy rainfall have at least kept the Ganga in high spate after it reached its peak on and after 24 August ?

(b) We note from Figure 15.1 that the movement of the depression between

22nd and 23rd was by far greater than between 21st and 22nd. Could not this persistence of the depression at one place and its subsequent considerable movement northwestwards be explained in a simpler way without invoking the aid of a system from the Chinese region ?

Figure 15.2 shows the upper winds and streamlines at 0.9 km a.s.l. over India north of 15° N on 21 August at 00 GMT. System extended upwards upto 2.0 km or more. The marked ridge of high to the west of the "Patna depression" may be specially noted. This high acted as a "solid barrier" and prevented the westward movement of the Patna depression.

Figure 15.3 shows the isopleths of departure of presure from normal at sea-level ove India at 03 GMT on 21 August. It will be noted that except in the region of the "Patna depression", the sea-level pressures were well-above normal over the country.

The high positive departures support the arguments about the "solid barrier" presented in the previous paragraph.

The upper winds and streamlines below 1.1 km a.s.l. at 00 GMT on 19th (not reproduced here) show convergence between the deflected monsoon northeasterlies and fresh monsoon westerlies between 76°E and 82° E North of 22° N. The convergence caused rather heavy rainfall in the tributaries of the Yamuna on its southern side. Table 15.2 shows the rainfall amounts reported on the morning of 19 and 20 August at some of the State-raingauge stations for which data were readily available.

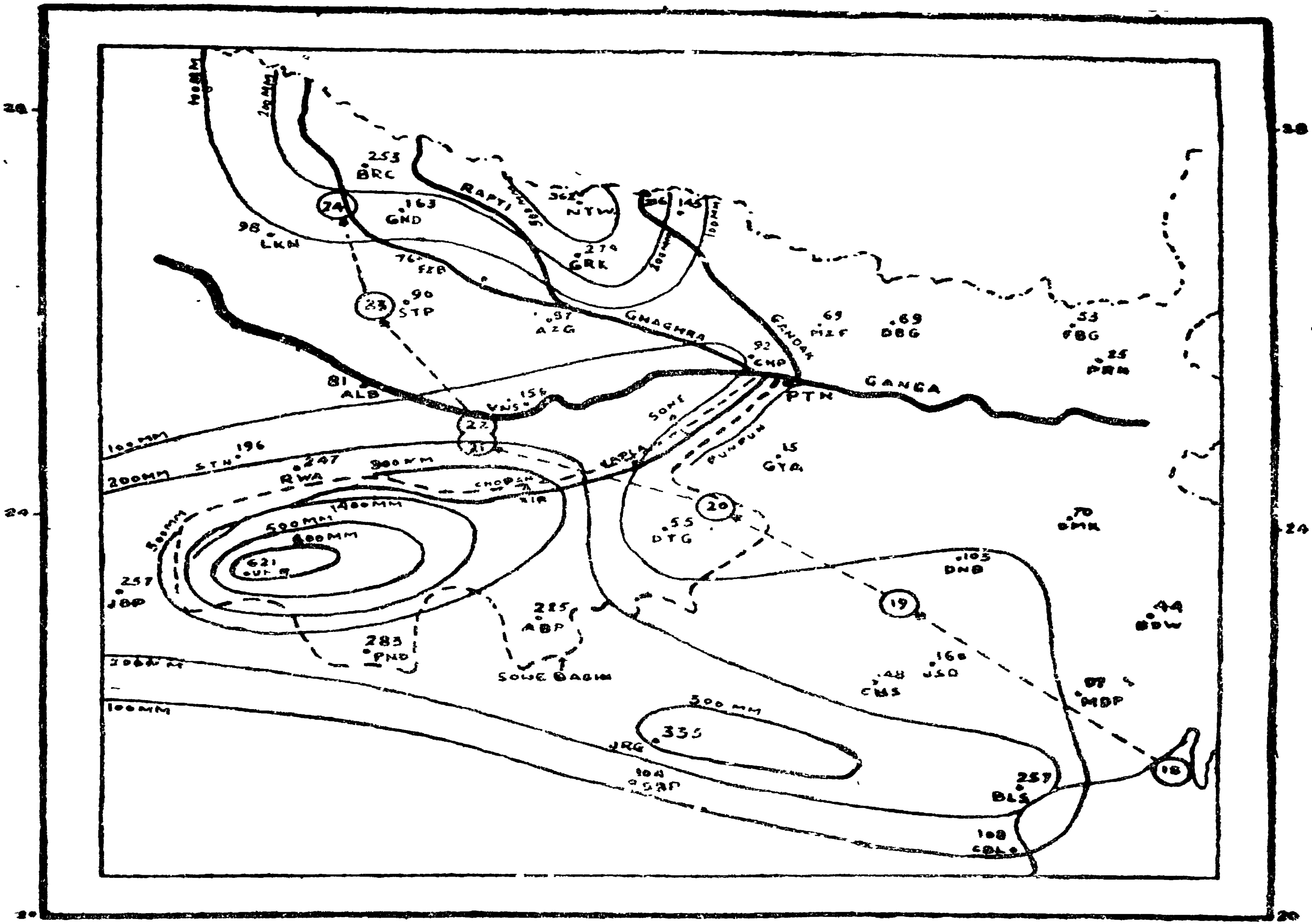
It stands to reason that the rainfall reported from the above stations on the morning of 19th and 20th would have flown downstream to Ganga near Patna (through the Yamuna) by the 24th. In other words, one cannot rule out the possibility of their having aggravated the floods near Patna. They would at least have kept the Ganga in high-spate on the 24th and 25th and even later.

Table 15.2 *Rainfall in 24 hours (whole cms)*

Name of Station	Catchment of river	Date of reporting of	Amount of Rainfall (cms)
Shivpuri	Sind	19 August	10
Tikamgarh	Betwa	-do-	7
Kota	Chambal	-do-	8
Tonk	Banas	-do-	4
Chittorgarh	Chambal	-do-	5
Kota	Chambal	20 August	6

Note :

There are several other stations in the catchments of tributaries on the southern side of the Yamuna which reported rain on 19th but other details required are not available.



28
24
20
253
BRC
163
GND
98
LKN
RAPTI
NTW
274
GRK
145
90
STP
GHAGHRA
AZG
GANDAK
69
MZF
69
DBG
53
FBG
25
PRN
92
CHP
GANGA
PTN
81
ALB
156
VNS
SONE
PUNPUN
15
GYA
196
STH
247
RWA
100MM
200MM
300MM
400MM
500MM
600MM
621
55
DTG
70
105
DNB
225
ABP
283
PND
257
JBP
SONE BASIN
44
168
JSD
CMS
MDP
300 MM
335
JRG
104
257
BLS
108

Figure 15.1

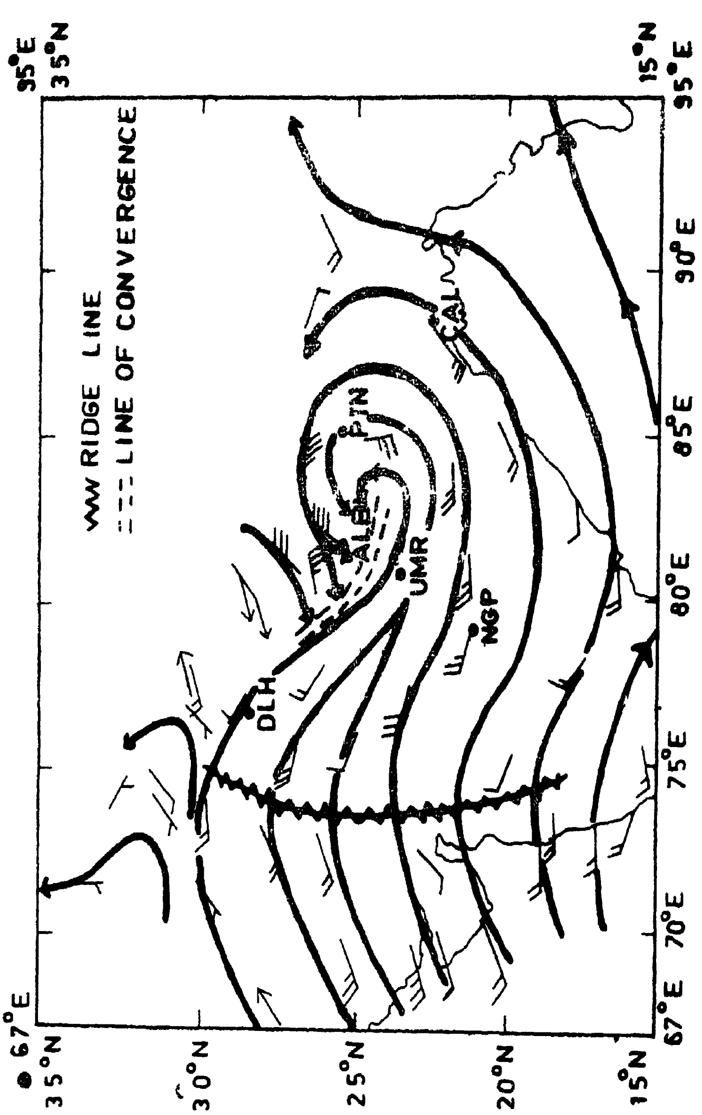


Figure 15 2 Upper Winds and Streamlines 21 Aug. 1975 00 GMT (0 9 km as 1)

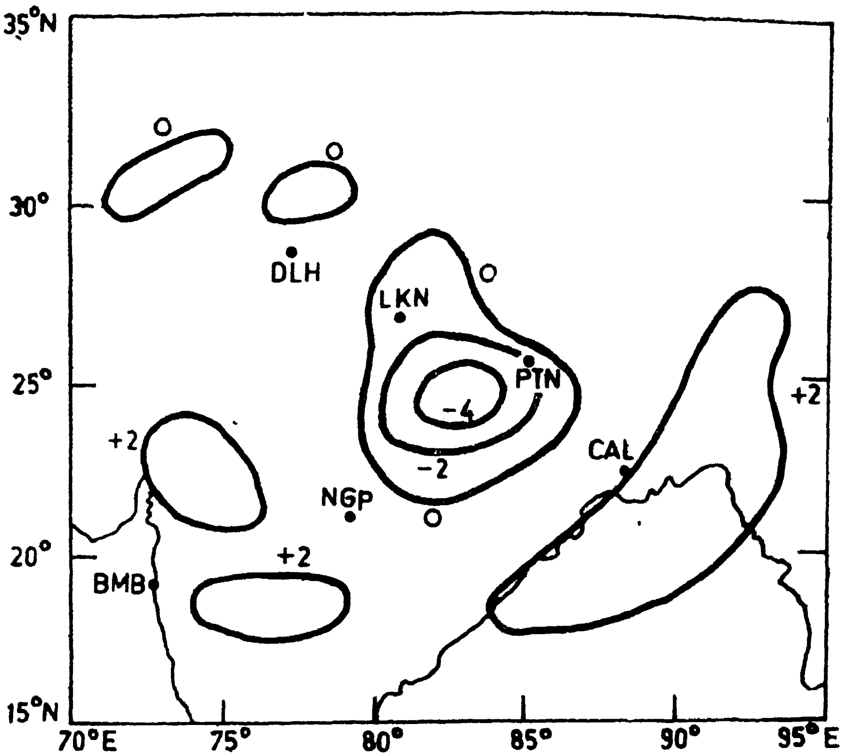


Figure 15.3 Pressurr Departure 21 Aug, 1075, 0300 GMT

Figure 15.4 shows the pressure-contours at the 250 mb level between 20°N and 45°N and between 55°E and 115°E on the morning of 21 August. While drawing these contours, we have relied far more on the winds than on the contour values on account of the well-known errors in radio-sonde values especially at these high levels in the tropics and sub-tropics. The 250 mb level was purposely selected as it lay *well-above the level of the cyclonic circulation* associated with the "Patna depression". The centre of the depression at sea-level on the morning of 21 August has been shown by the symbol C_{21}. The low pressure area between 95°E and 115°E (Chinese low referred to by Prasad and Sen Sarma) may also be seen in the same diagram.

It will be noted that the winds on the southern side of the Tibetan high to the east of Lucknow are light. The steering effect (wastwards initially) on the "Patna

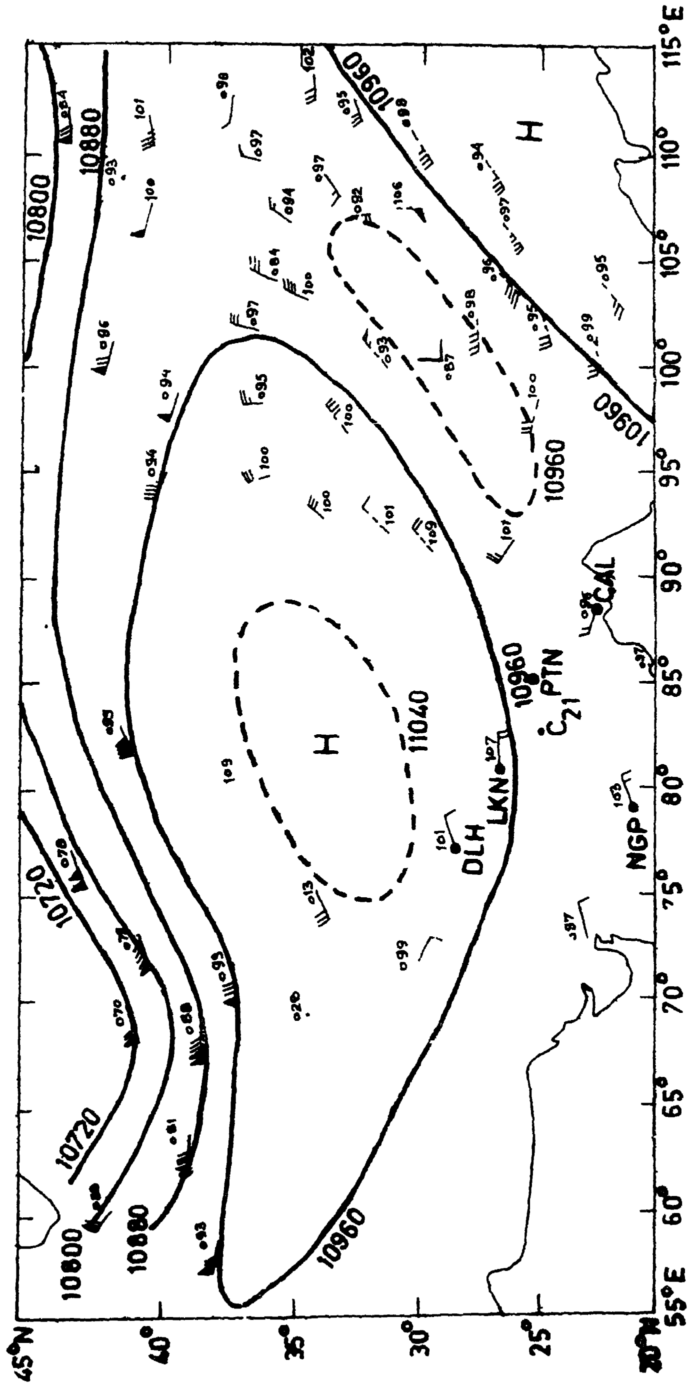


Figure 15.4 250 mb 00 GMT of 21 Aug. 1975

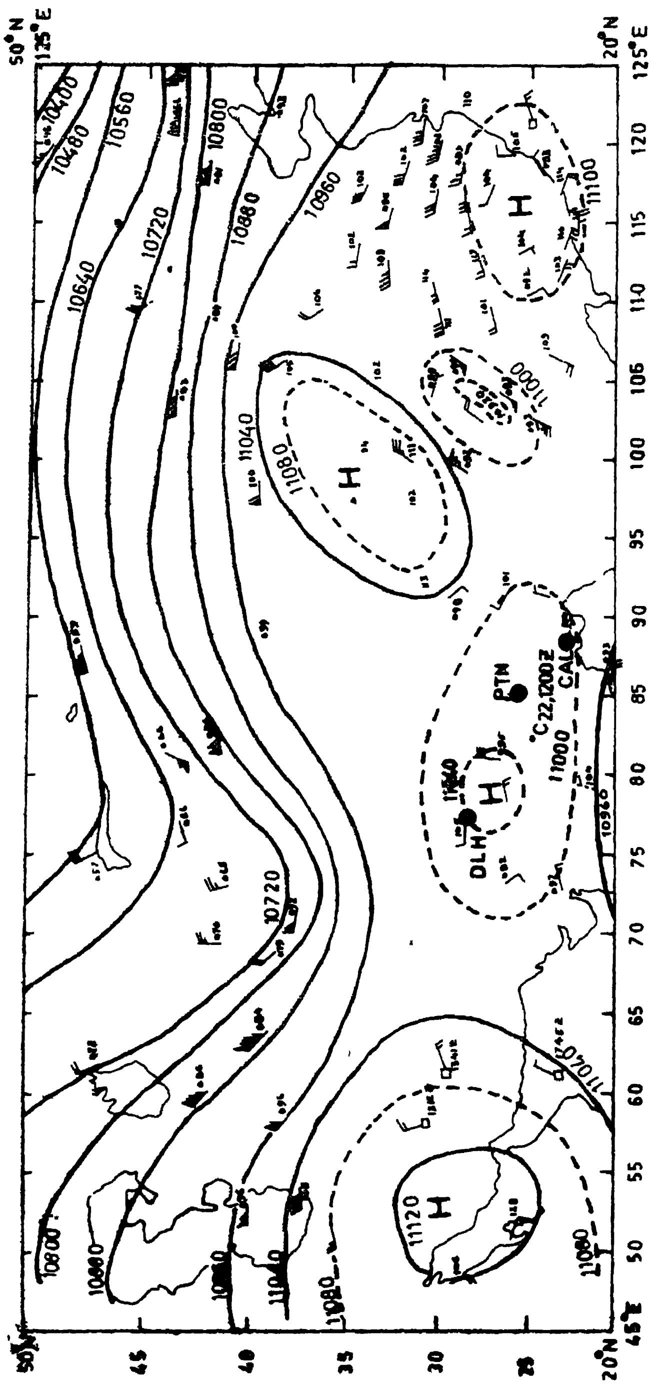


Figure 15.5 250 mb 1200 GMT 22 Aug 1975

depression" would therefore have been small. Apart from this, the "solid barrier" in the lower troposphor which was persistent, would have acted as a break on the movement of the depression westwards.

Figure 15 5 shows the 250 mb perssure-contour pattern at 12 GMT on 22nd. The errors in radio-sonde values pointed out earlier are equally applicable in this case. The centre of the "Patna depression" at 12 GMT on 22nd evening has been shown as $C_{22,1200}z$. The Chinese trough (Prasad and Sen Sarma, 1978) and the subtropical high over China split into two may also be seen in the same diagram. But the important point to be noted in this diagram is that the anti-cyclonic cell over the Tibetan plateau is *an entity in itself.* The Patna depression curved round the high faster than it could have done on tne 20th The sea-level pressure-departures also continued to be well-above normal. In fact, it was markedly above normal even on 25th August. This would therefore have been an additional factor preventing the westward movement of the Patna depression and thus indirectly helped the northwestward movement of the depression. It will thus be seen that the persistence of the Patna depression without much movement on 21 and 22 Agust and its later considerable movement northwards can be explained without bringing the Chinese weather systems into the picture. The author is of course fully aware of the mutual interactions of even distant weather systems, (atmospheric teleconnections e. g. Ramaswamy 1972) He is also aware that the steering concept as stated by us, is even now not beyond controversy (Ramaswamy 1972). But in the absence of any better tool which may be evolved in future using theoretical concepts for the tropics and sub-tropics, the author would like to utilise the steering effect by high level circulations *above* the level of the low level weather systems, as a practical tool in forecasting.

More than a decade ago (Ramaswamy 1968) the author had shown with synoptic iillustrations the curving of monsoon depressions around highs. In later years, he had also shown in a number of papers with synoptic illustrations (i. e. Ramaswamy 1972) that the flow patterns above the level of the cyclonic circulation serves as a practical tool for predicting the steering of monsoon depressions. The present case merely serves as one more illustration.

5. Anallysis of Satelite Picture

Plate 15.6 shows the A.P.T. picture recorded by NAOA-4 on 22.8.75 at 10 hours 10 minutes I.S.T. The dense mass of convective clouds between 20°N and 25°N and between 78°E and 85°E shows the heavy rainfall which must have occurred on the 22 August and earlier.

6. Flood Damage

The following account of the flood damage has been taken from the paper of Sen Sarma and Prasad.

The floods caused large scale damage to life and property. According to official figures, 17 human and 73 cattle lives were lost and 24207 houses collapsed. Crops

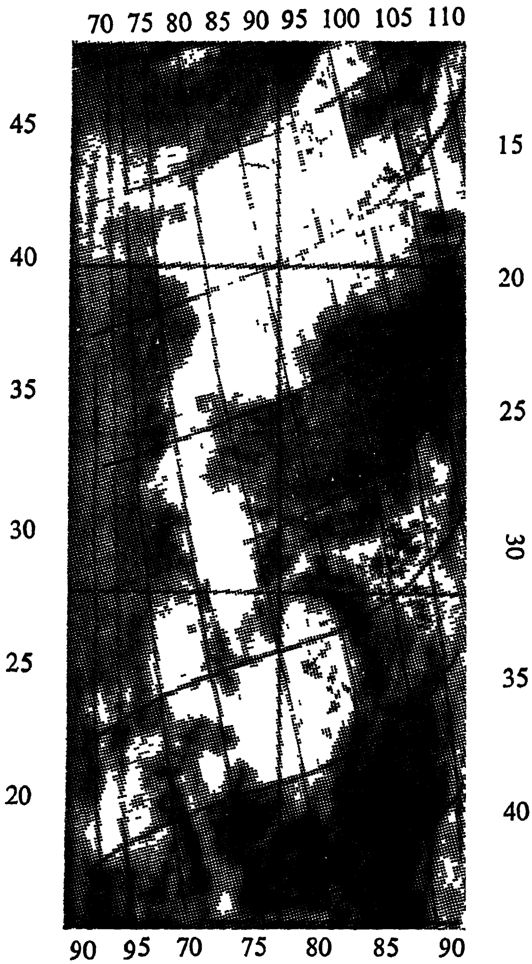


Figure 15 6

valued Rs. 212.5 lakhs were destroyed. The entire complex of Patna township excepting its extreme eastern parts were submerged to a depth of 2 to 4 metres.

The flood-affected areas in Patna included some of the most affluent and fashionable residential localities of the town, most of the Government offices belonging to the State and Central Governments, residential buildings occupied by the dignitaries in the Government of Bihar, Patna Secretariat complex, Patna Airport, Banking and financial institutions in the capital, Patna main telephone exchange—to name only a few important ones. Water entered Patna Secretariat, the seat of Bihar Government, 4 to 5 feet deep spoiling some of the valuable and rare documents. In some localities, the residential buildings were submerged 8 to 10 feet deep forcing the ground floor residents to take shelter on roof-tops. Thousands of vehicles remained submerged in

water for several days. Electricity and water supply was disrupted. Vital installations were badly damaged. Surface communications snapped.

To add to the miseries, Ganga which takes not only the discharge from Sone but also the storm water flow from Patna township, continued flowing high for a long period after the inundation. This culminated in blocking of natural gravity drainage of accumulated flood waters from the town. Accumulated water, as a result persisted for about 10 days and in some parts as many as 15 days. Stagnant pools of water formed in the low-lying areas which had to be pumped out with the help of about 200 pumping sets and by cutting roads at strategic points.

CASE No. 16

CATASTROPHIC FLOODS IN THE DISTRICTS OF MADURAI, PUDUKOTTAI AND TIRUCHIRRAPALLI DISTRICTS IN TAMIL NADU IN NOVEMBER 1977

1. Introduction

This is a case of special interest as it was associated with a severe cyclone which not only caused very high winds but also caused flash floods (I. Met. D., 1980).

2. Hydrological Information

It is unfortunate that no hydrological information is available in respect of this case, presumably because it was a case of Flash floods.

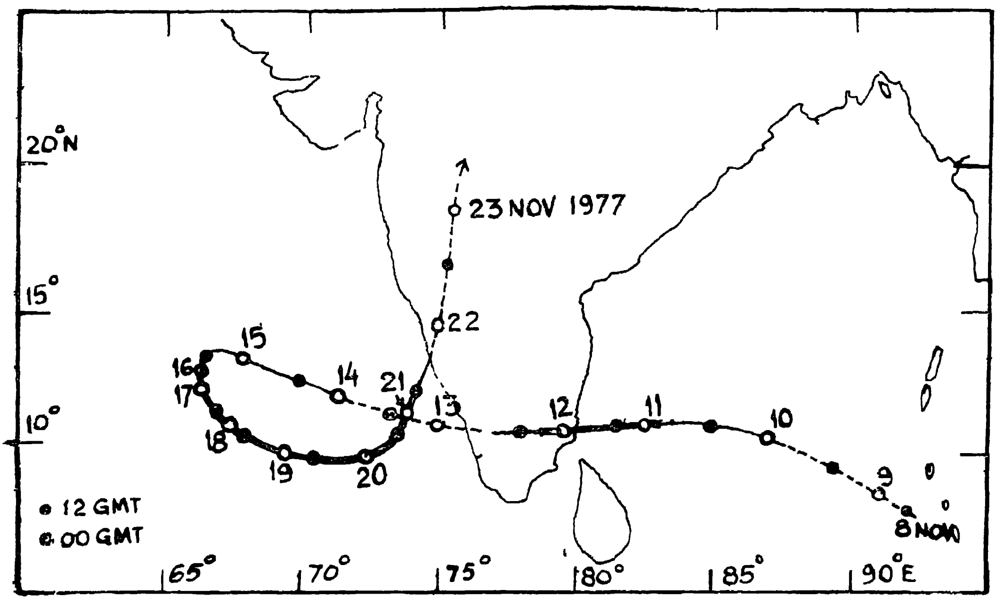


Figure 16.3 Track of Severe Cyclone in Bay of Bengal & Arabian in Sea November 1977

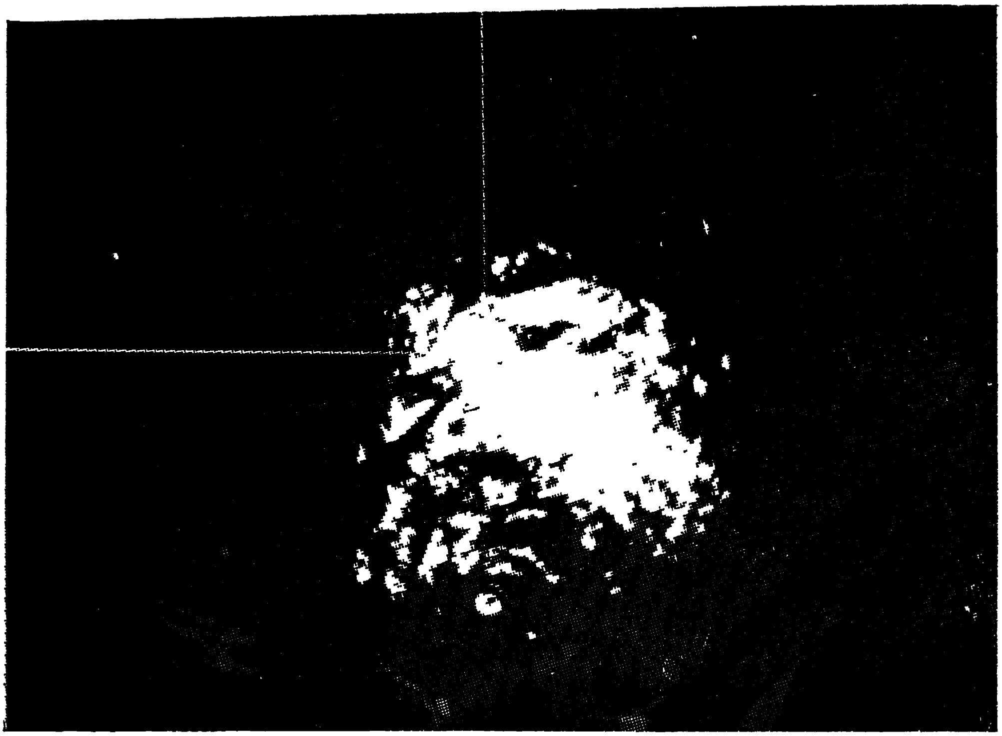


Figure 16 2

3. Large-Scale Synoptic Situation

The antecedent conditions were not unfavourable. The flash floods were caused by a severe cyclone from the Bay of Bengal which struck Nagapattinam. The cyclone performed a remarkable loop after it entered into southeast Arabian Sea. The complete track of the cyclone may be seen in Figure 16 1. The radar picture of the cyclone as seen by the storm-detecting radar at Madras is shown in Figure 16.2. A brief summary of the cyclone so far as it is relevant to the study of the floods is given below.

In association with a low pressure wave which moved westwards across south Andaman Sea, on 8th Novermber 1977, a depression developed with its centre near 8°N 92°E. Moving northwards initially and in a westerly direction later, the depression developed into a severe cyclonic storm on the morning of 11th. The severe storm struck the Tamil Nadu coast just to the south of Nagapattinam (Figure. 16.1) in the early morning of 12 November (around 2230 GMT of 11th). The system weakened into a cyclonic storm by the same evening over the interior of Tamil Nadu, and emerged into Lakshadweep off North Kerala coast on the morning of 13th as a deep depression. The further history of this cyclonic system is of no special interest to us in our present study. We will not therefore describe it here.

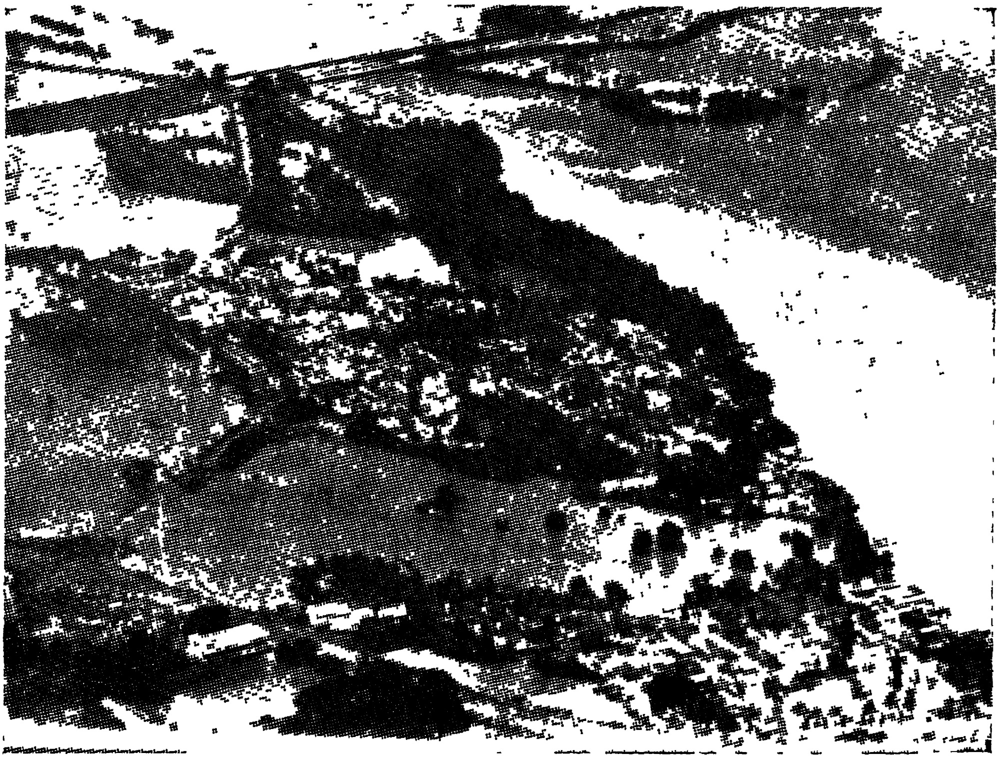


Figure 16.3

4. Rainfall Analysis

Nagapattinam reported an exceptionally heavy rainfall of 32 cms in 24 hours ending at 0830 I S T on 12th. Some places in Thanjavur, South Arcot, Salem, Tiruchirra-palli, Pudukottai and Madurai districts reported 24 hours rainfall ranging from 12 to 19 cms on 12th and 13th.

5. Flood Damage

The districts in the State of Tamil Nadu which were most affected by floods were Madurai, Pudukottai and Tiruchi. 500 persons were reported to have lost their lives mainly due to flash floods.. House-collapses and 23000 heads of cattle including sheep and 5000 poultry perished. Crops over an area of 4 lakh acres were affected and the damage was estimated to be about 42 crores of rupees. Total value of damage to private and public property was estimated to be about 155 crores of rupees. Train services in the Sothern railway were dislocated due to breaches in the railwaytrack. The railway bridge on the *Amaravathi* river near Karur was washed away. A photo-graph of the flood-hit Srirangam (one of the most sacred Hindu religious sites in South India) may be seen in plate Figure (16.3).

CASE No. 17

CATASTROPHIC FLOODS IN GANGETIC WEST BENGAL IN THE LAST WEEK OF SEPTEMBER 1978

1. Hydrological Information

It is unfortunate that hydrological information available in respect of this case is inadequate. Dhar & Ghose (1979) have given hydrological data in respect of the river Dwarkeswar in West Bengal in the last week of September 1978. The gauging site at Arambagh recorded only 1.92 metres above the danger level as the highest flood level in the last week of September 1978. This figure is lower than the lowest limit (2 metres above danger-level) specified by us for the study of "severe" floods. No flood-level data recorded in the Hooghly at Garden Reach, Calcutta were available. On a general survey of the information collected by us especially from Press Reports, we cannot resist the impression that the catastrophic floods and inundations experienced in Gangetic West Bengal on this particular occasions must have been at least partly due to excessive discharge of waters from the Damodar Valley Corporation and other storage reservoirs. They may also possibly be due to breaches in embankments in certain areas.

2. Large Scale Synoptic Situation

2.1 Antecedent conditions:

The flood-situation occurred towards the end of the monsoon season by which time, the sub-soil would have become nearly saturated with rain water. In particular, it may be mentioned that a deep land-depression had caused heavy rainfall and floods in Gangetic West Bengal between 1 and 5 September. The antecedent conditions were therefore very favourable for the over-flow of the rivers in West Bengal in the last week of September.

2.2 Details of the actual synoptic situation :

A low pressure area moved westwards across Tenasserim coast into North Andaman Sea on 19 September. It concentrated into a depression on the morning of 21st with its centre at 00 GMT about 50 km southeast of Balasore. The depression crossed the Orissa coast near Balasore and lay over the interior parts of North Orissa on the same evening as a 'low'*. The latter persisted over northeast Madhya Pradesh and the adjoining parts of Bihar and South Utter Pradesh from 22nd to 25th. It concentrated again into a depression on the morning of 26th over Bihar its centre east of Daltonganj (24°03′ N, 84°04′E) (Figure 17.1). It moved *eastwards* and became a deep depression over Gangetic West Bengal on 27th. Later it moved slowly across Gangetic West Bengal southeastwards on southwards and emerged into northwest Bay

*As the cyclonic system was a depression only for one day near Balasore, the I. Met. D. (1979) have not shown it in their diagram containing the storm tracks and depressions in 1978. We have however, included the entire track in Fig 17 1. schematically as a zig-zag curve.

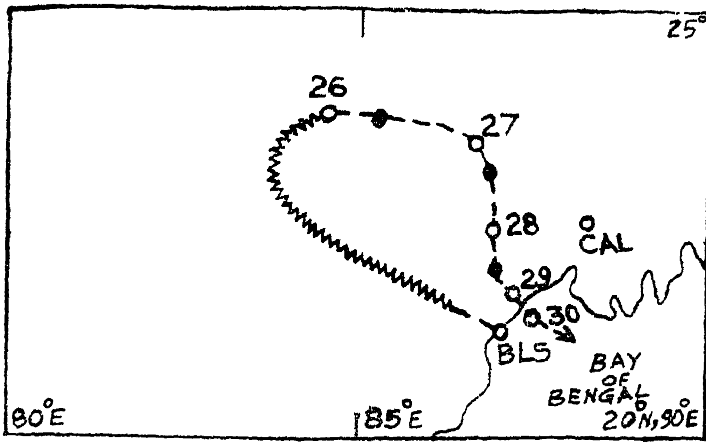


Figure 17.1 Track of West Bengal Depression 26-30 Sep 1978

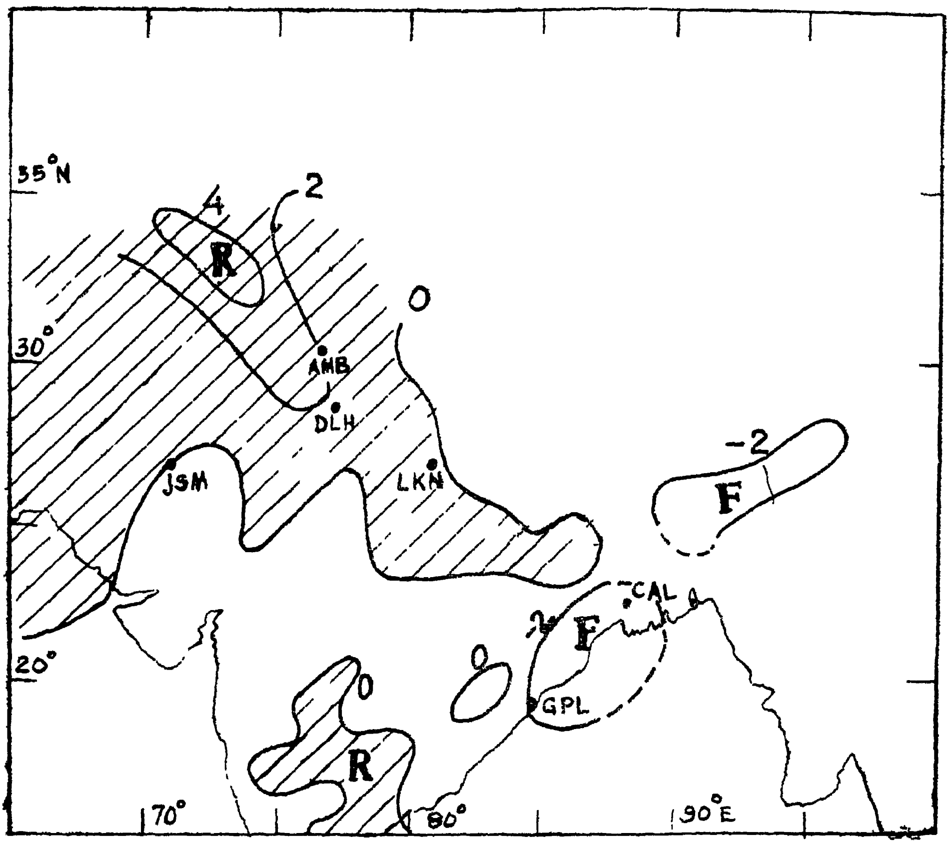


Figure 17 2 24 Hours Pressure Changes 03 GMT 27 Sep 7003 GMT 28 Sep 1976

of Bengal as a depression on the morning of 30th. It weakened further thereafter and became unimportant on 1st October. The track of the entire cyclonic storm from off the Orissa coast and back into northwest Bay is shown in Figure 17.1.

2.3 Why did the depression move eastwards initially over Bihar plateau and southwards later over Gangetic West Bengal :

Figure 17.2 shows isopleths of pressure-changes at sea-level from 0300 GMT of 27th to 0300 GMT of 28th. Figure 17.3 shows the upper winds and streamlines at 2.1 km level at 00 GMT on 28th. It is obvious from these diagrams that the pronounced

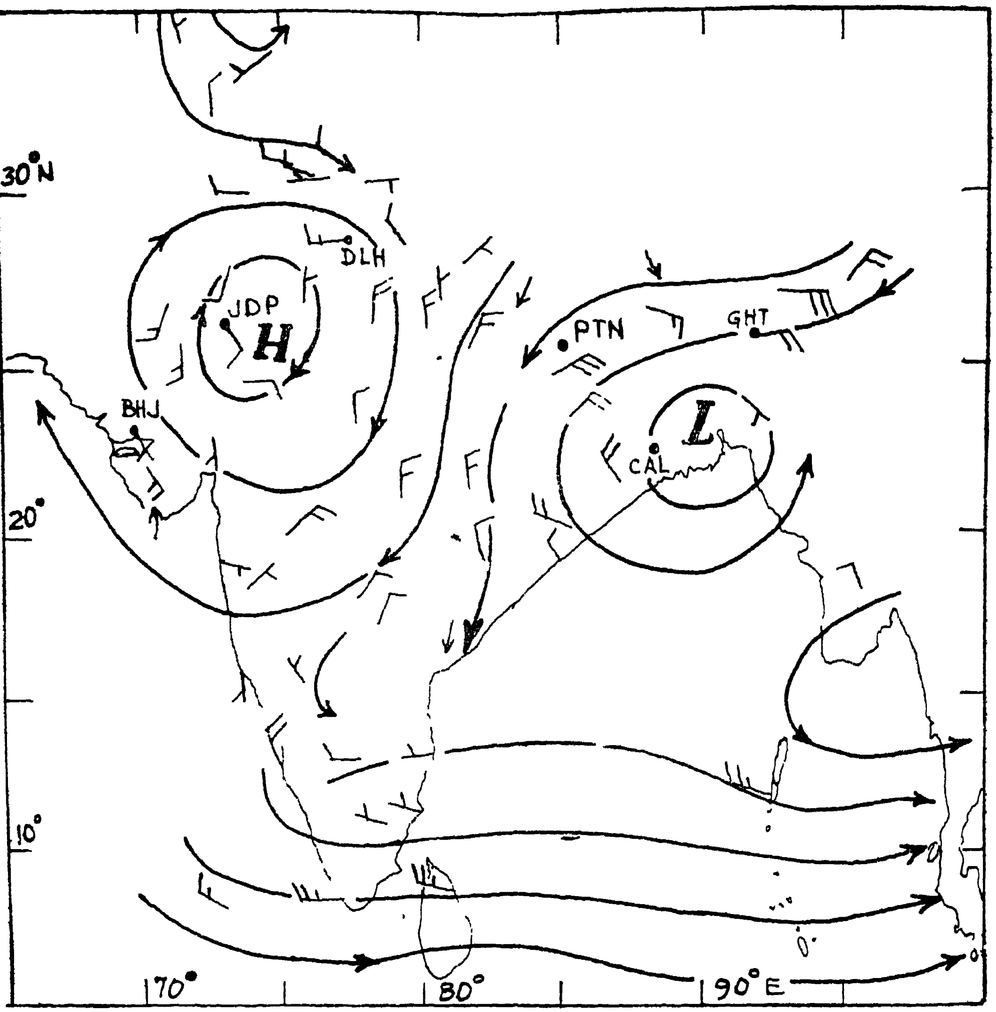


Figure 17.3 Upper Winds & Stream-Lines 00 GMT on 28 Sep 1978 2.1 km

high over Rajasthan and the central parts of the country in the lower troposphere acted as a barrier and did not allow the land-depression to move westwards.

Figure 17.4 shows the 300 mb contours at 00 GMT on 28th. The data of winds and contour-values may not be free from errors due to mutilations during transmissions. The position of the centre of the depression at sea-level at 0300 GMT on the 28th has been marked by the latter "C" on the diagram.

The 300 mb level in the present case lay above the level of the cyclonic circulation and hence we may proceed on the basis (Ramaswamy, 1972) that the wind layers near about this level would have initially steered the depression eastwards and later southwards.

The slowness of the movement of the depression after the 27th is partly explained by the low speed of the westerlies at the "steering" level. The depression therefore persisted for a long period over Gangetic West Bengal. The persistence resulted in an increase in the inflow of monsoon air at sea-level into the field of the depression and resulted in its further intensification over Gangetic West Bengal. The high to the west of 85°E with its core over Northwest Madhya Pradesh and East Gujarat and the NNE wind at Jamshedpur at the 300 mb level may also be particularly noted. Such a position and configuration of the 300 mb level with N/NE wind ove Jamshedpur had not occured on any day prior to 28th September.

The general mean pattern in the month of September at the 300 mb level may be seen in the Meteorological Atlas of the I.I.O.E. Expedition (Ramage & Raman 1972). Although it relates to the I.I.O.E. period 1963-1965, the mean conditions as revealed by the I.I.O.E. Atlas are representative, enough to show that the actual conditions as seen in Figure 17.4 differed significantly from the September mean conditions.

An examination of the tracks of the cyclonic storms and depressions over the Indian seas published by the I.Met.D. (1980) also reveals that there has been no such case of southerly movement of a depression from Gangetic West Bengal into the Head of the Bay during the last 100 years.

3. A Phenomenal Type of Monsoon Depression—Only one of its kind in the last one Hundred years

The author is convinced that such an unusual movement could not have been an isolated development in Northeast India. It should, in our opinion, have been associated with largescale changes in the General circulation over the Globe particularly in the Northern Hemisphere. A study of this aspect can be made only by examining regions where plenty of surface (including sea-surface temperature) and upper air data are available. The U. S. A. is a region over which maximum data are available. The U. S. Monthly Weather Review maps and the progressive variations in the mean flow patterns during the successive weeks as published therein were therefore studied in the first instance. Figure 17.5, 17 6, 17.7 and 17.8 show the mean 700 mb flow patterns during successive 5-day period (5-9 September) to the fourth five-day period (26-30 September). The mean trough had moved eastwards from 125°E to 85°E during a

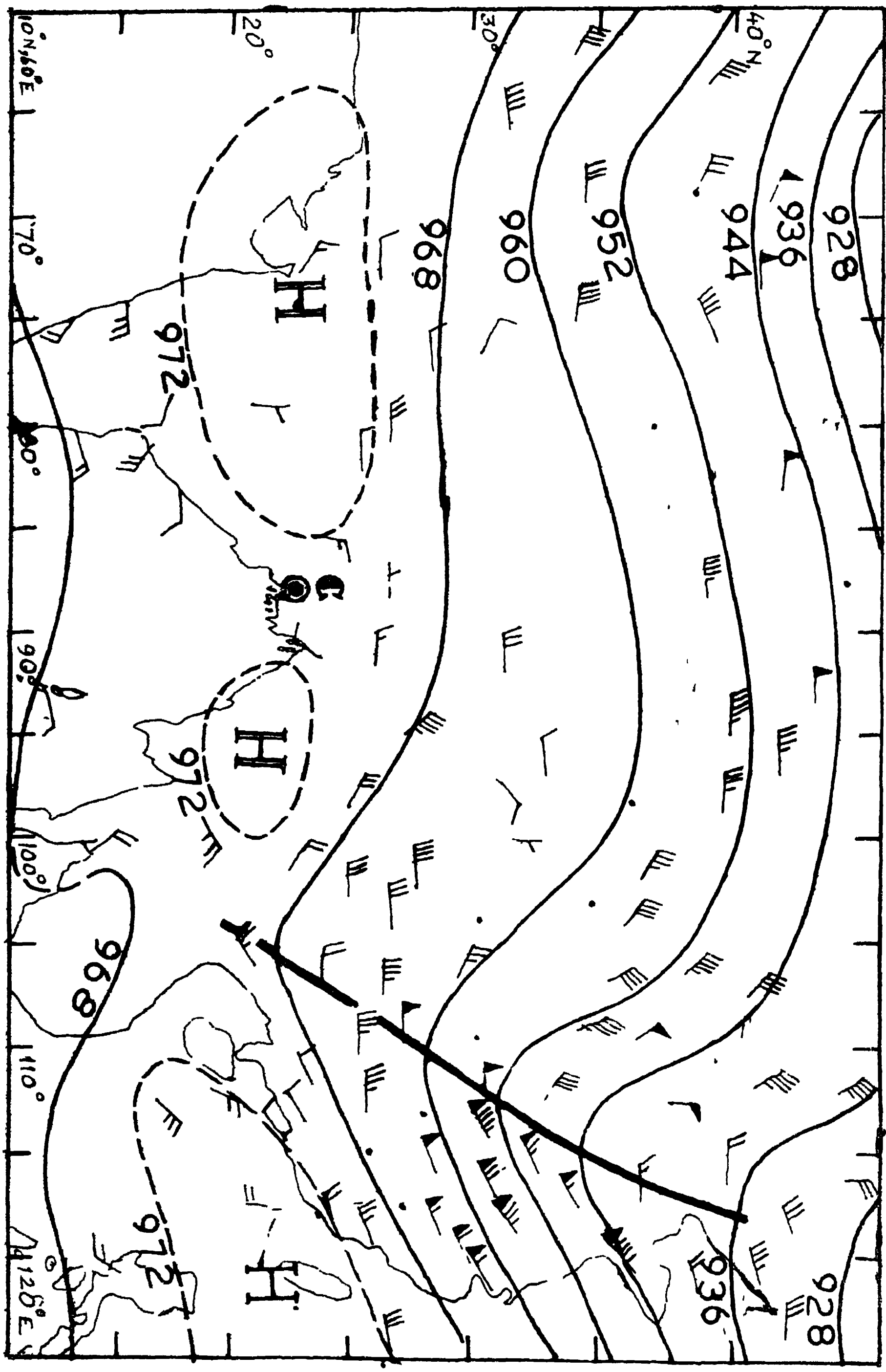

10°N,60°E
20°
30°
40°N
70°
90°
100°
110°
120°E
968
960
952
944
936
928
972
H
C

Figure 17 4

period of 21 days. Simultaneously with this movement, the ridge of high in the rear of the trough had also moved eastwards. During the period 26-30 September, the area south of 40°N was a region of high with two closed anticyclonic cells.

With regard to precipitation, the following quotations from the paper by Taubensee is relevant :

(Extract from p. 1755 of U.S. Monthly Weather Review for September 1978).
25th September to 1st October.

"A ridge in the west together with preponderance of generally northwesterly 700 mb flow centributed to a relatively dry week over a large part of the country (Figure 17.9 in our monograph). Heaviest precipitation was confined mostly to the Gulf States in response to several short wave troughs and week tropical activity."

In the last paragraph of the same paper, Taubensee has stated the following :—

"Heavy monsoon rains caused massive flooding in Northern and Eastern India. More than 1100 people were reportedly killed by the floods and damage-eastimates exceeded 100 million dollars. Taubensee was obviously referring to what had taken place in West Bengal in the last week of September 1978. In this connection the following extract from the I.Met.D. publication "Mausam" (October 1980 issue) is relevant :

"Very heavy rain over Calcutta for three consecutive days from 27th to 29th amounting to 72 cm caused a deluge in the city and paralysed the life in the ciy. According to press reports, unprecedented flood affected all the 12 districts in South Bengal, partly due to heavy discharge from DVC, Mayurakshi and other dams and partly due to locally heavy rain. Road and rail communications between Calcutta and rest of the country were cut off. Jute and cotton textile and engineering industries in Greater Calutta and Durgapur-Asansol industrial complex were seriously affected. The coal fields in Raniganj and Jharia were inundated About 1,000 people were killed due to floods and house-collapses in West Bengal. Heavy damage was caused to crops, houses and other property".

The reports published in the U.S. Monthly Weather Review as well as in "Mausam" refer to the death of about 1000 people due to floods. The author of this monograph can also state from his personal knowledge that in no other part of India did 1000 people lose their lives due to floods in *September 1978*. We can therefore safely presume that the period "early in September" as given in the U.S. Monthly Weather Review by Taubensee is an inadvertent error in the publication in U.S.A.

4. Did the heavy Rainfall and Floods in west Bengal in the last week of September 1978 have possible atmospheric Teleconnections with weather Development in west United States ?

In publishing the large-scale flow patterns over U.S.A. and adjoing areas and in our making a camparative assessment of the flood havoc in West Bengal as

*The complete 5-day mean 700 mb chart for the period 26-30 September later supplied by Dr. Taubensee shows a diffuse low over Northern India and Pakistan with highs over China and uppee Burma and over North Arabia and Iran.

published in U.S.A. and in India, it is not to be assumed that we have proved that there were atmospheric teleconnections between weather developments in India and U.S.A. The problem is yet to be studied in depth. We have therefore already taken up this aspect separately for study. Unfortunately, the data available at the moment over the north African region are very inadequate. Attempts are being made to collect data from the African region and any new conclusion concerning atmospheric teleconnections which we may arrive at, will be published elsewhere.

5. Rainfall Analysis

The following are the neteworthy amounts of 24 hours rainfall ending at 0300 GMT as recorded over Gangetic West Bengal and Bihar plateau in the last week of September 1978 :— (Table 17.1)

Table 17.1

Date	Station	24 hrs. rainfall (cms)
26th	Hazaribagh	12
27th	Sriniketan	34 (Record)
,,	Panogarh	33 (Record)
,,	Dumka	30
,,	Dhanbad	23
,,	Calcutta	22
,,	Bankura	18
,,	Uluberia	16
,,	Magra	14
,,	Krishnanagar	14
,,	Balasore	13
,,	Midnapore	13
28th	Calcutta (Alipore)	37
,,	Dumdum	33
,,	Magra	28
,,	Sriniketan	17
,,	Diamond Harbaur	15
29th	Krishnanagar	15
,,	Calcutta	13

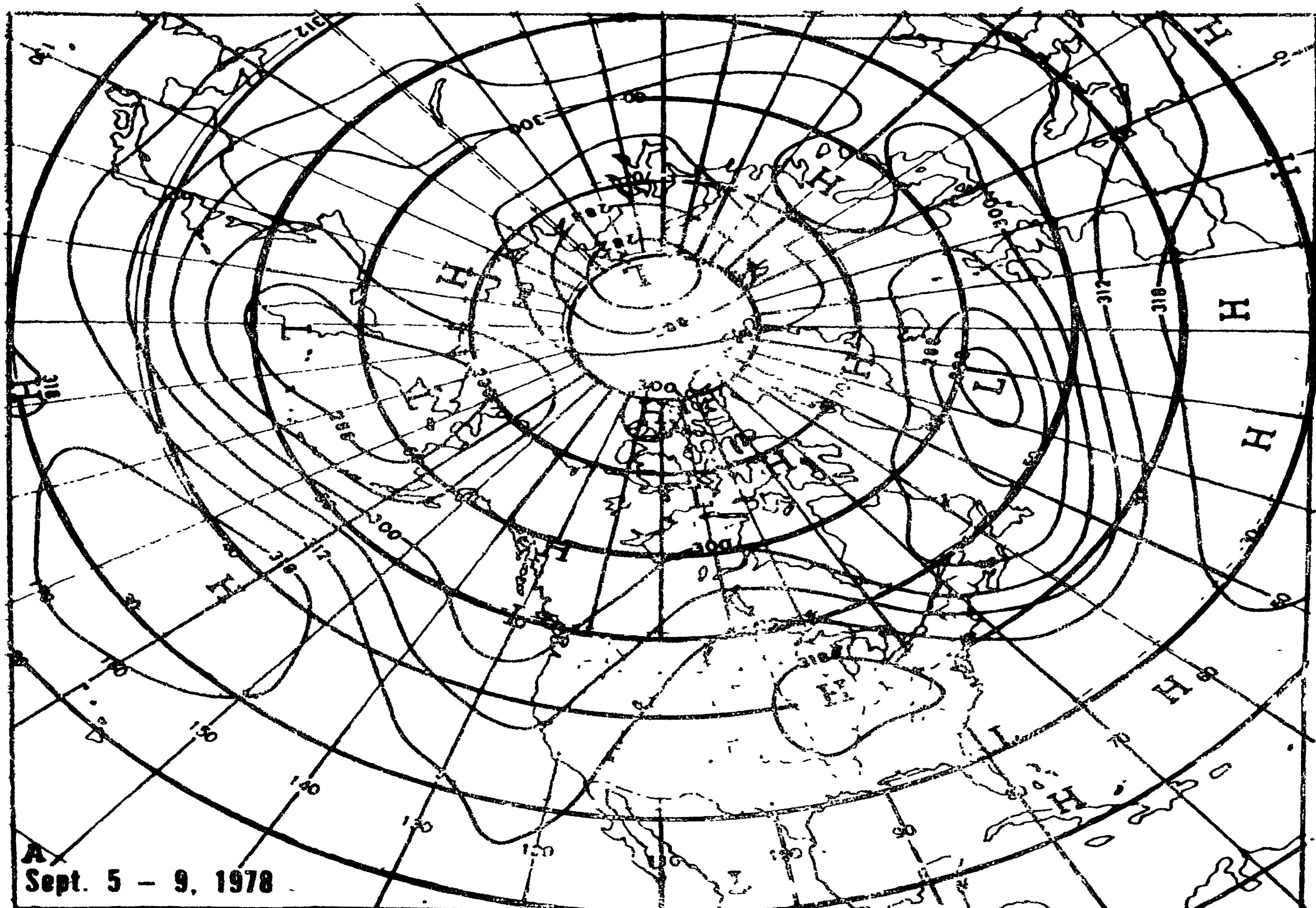


Figure 17.5

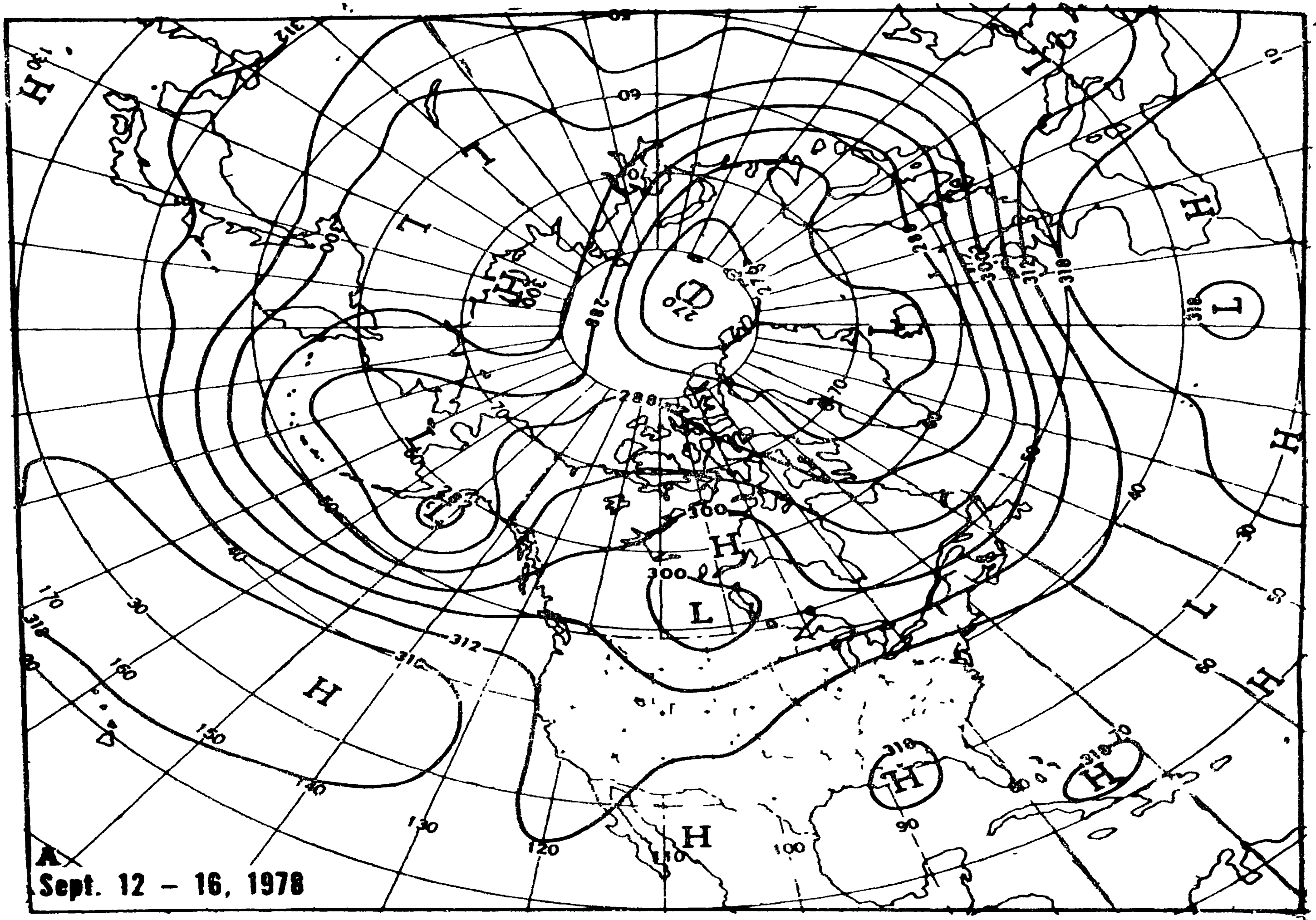


Figure 17 6

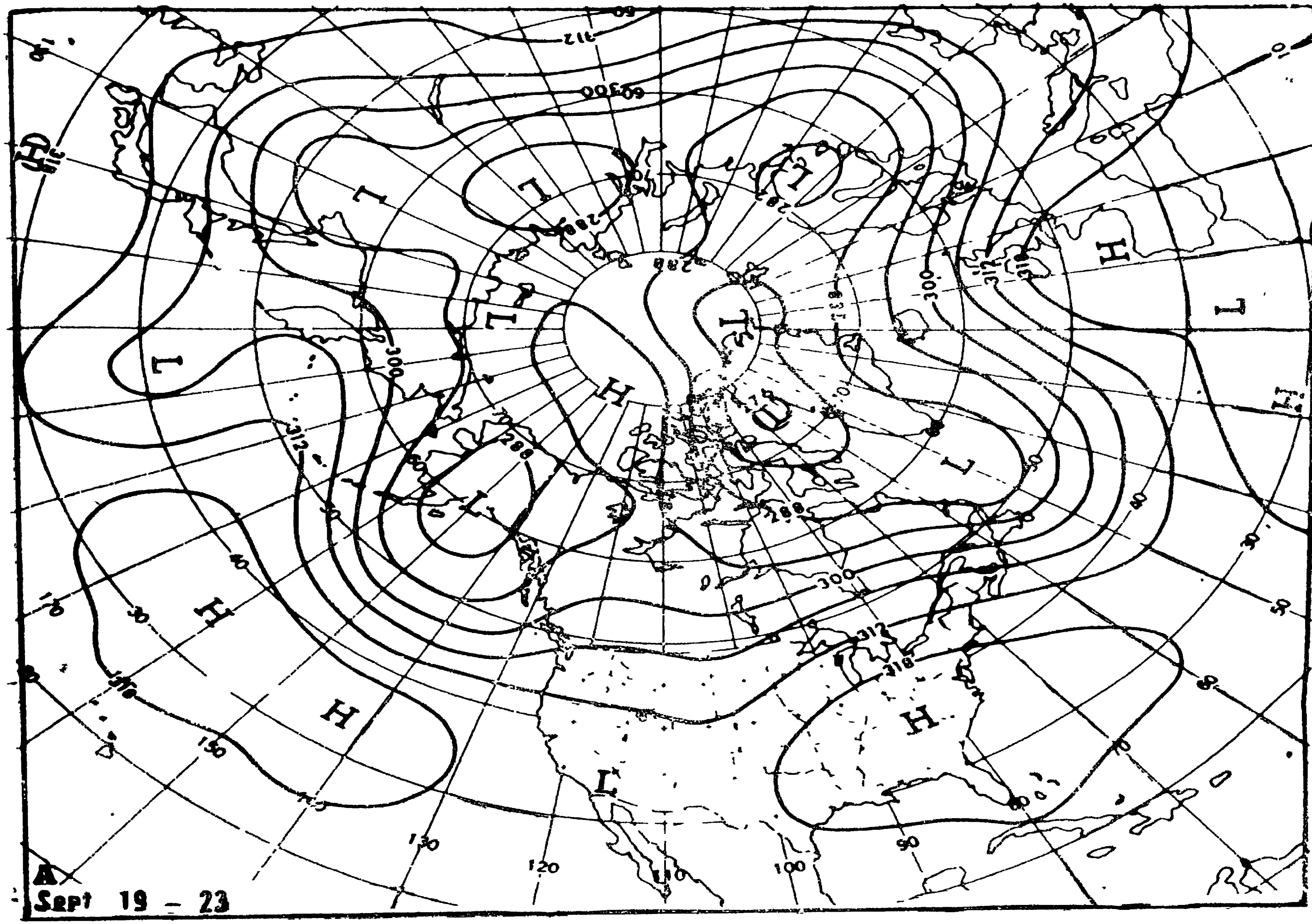


Figure 17.7

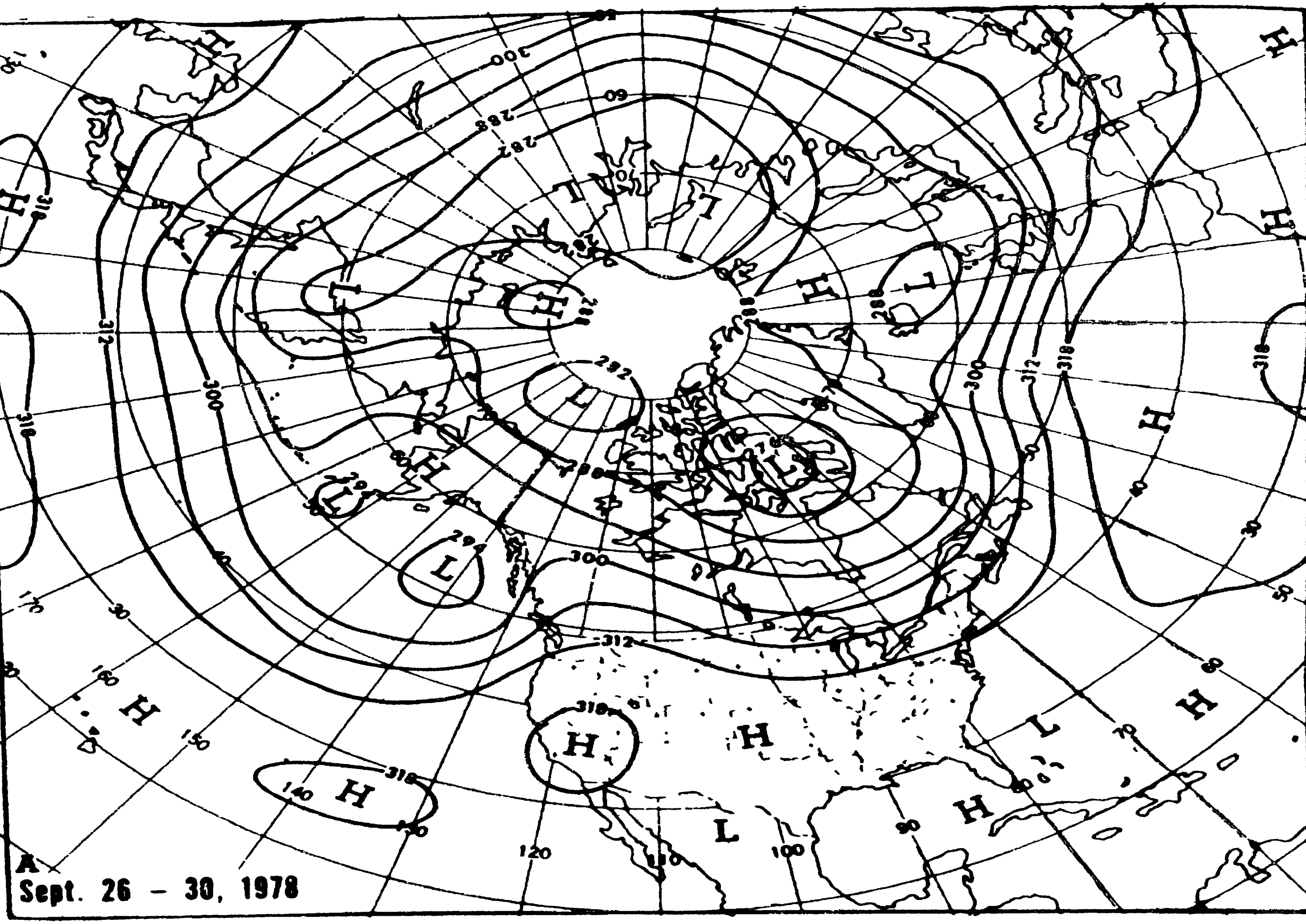


Figure 17.8

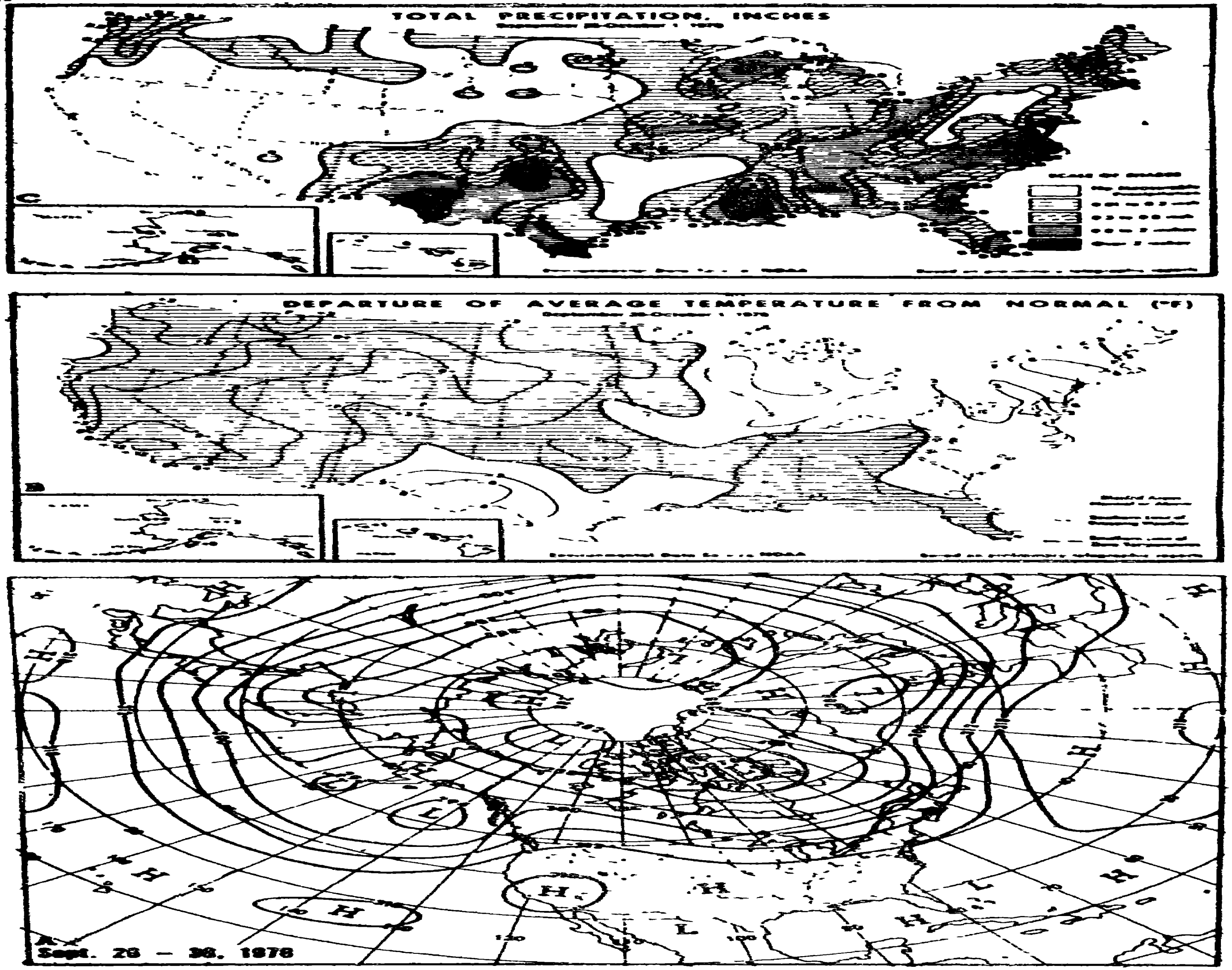

TOTAL PRECIPITATION, INCHES
C
DEPARTURE OF AVERAGE TEMPERATURE FROM NORMAL (°F)
B
A
Sept. 26 – 30, 1978

Figure 17.9

Satelite Weather Analyis

APT pictures were not available on 26th and 28th. These were the most important days from the point of view of our study. The other pictures are of little interest and are therefore not being discussed here.

6. Flood Damages

An account of the flood-damage in West Bengal and the Bihar plateau has already been given by us earlier in another section. Hence we are not repeating them here.

CASE No. 18

CATASTROPHIC FLASH FLOODS NEAR MORVI IN SAURASHTRA IN AUGUST 1979

1. Introduction

This case is very tragic one as it was associated with the bursting of a dam which resulted in flash floods and colossal loss of human lives and property. The dam referred to, is across the Machhu river in Saurashtra. This river rises in the hills of northern Kathiawar and has a total length of 140 km. There are two dams across this river and we shall refer to them as Machhu-1 and Machhu-2. (Figure 18.1). It was Machhu-2 which burst in the afternoon of 11 August between 1430 and 1500 IST and caused the tragedy. The precise reasons for the bursting of the dam are not known to the writer but there can hardly be any doubt that the very heavy rainfall which occurred over that area must have been one of the major causes of the disaster. The facts connected with the very heavy rainfall are discussed in the following sections.

2. Hydrological Information

Dhar et al (1981) have made an exhaustive study of the hydrometeorological aspects of this case. We have therefore freely drawn from their paper and have included extracts from the same in our monograph.

According to Dhar et al. the Machhu-2 dam was designed to pass a peak flood of 5.7×10^{3} m^{3} sec^{-1}. However, on 11 August 1979 it was reported that a peak flood exceeding 1.4×10^{4} m^{3} sec^{-1} which resulted in the overtopping of the earth flanks of the dam on the afternoon of 11 August 1979 between 1430 and 1500 hours IST

The worst affected area was Morvi town and the neighbouring villages about 6 km downstrean of the dam where a flood-wave of 8-10 metres in height rolled down from the damaged Machhu dam, submerging everything in its path.

On the basis of a detailed study of past severe rain-storms during the past 80

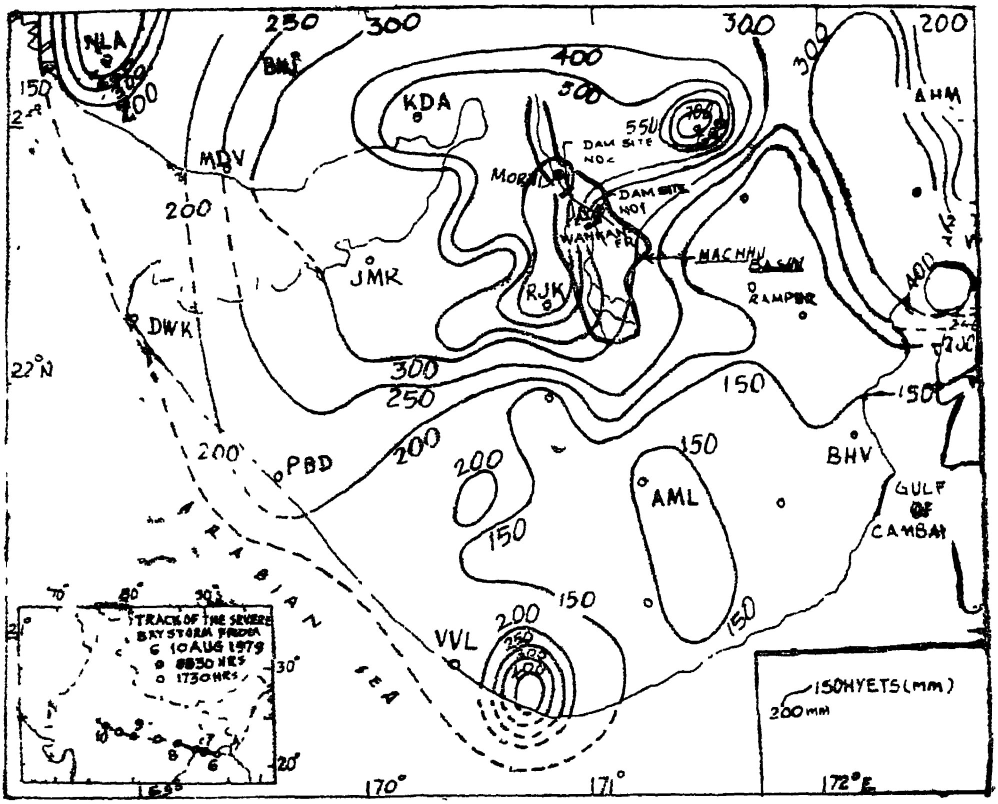


Figure 18.1

years, Dhar et al. have drawn several conclusions. The following is quoted from their summary and conclusions : "During the period 10-12 August 1979, Machhu basin up to Machhu-2 dam received about 4 times the normal basin rainfall for August. Depth-duration analysis of past rainstorms over this basin has revealed that the July 1927 rainstorm gave maximum rain depths for durations of 1 and 2 days while the 10-12 August 1979 rainstorm gave maximum rain depths for 3-days duration. Depth-area-duration analysis of the past severe rainstorms of this region has shown that, by and large, the July 1927 rainstorm was the most severe one and the rain depths measured in this storm were much higher than in the rainstorm of 10-12 August 1979. Apparently, the large volume of water generated during the rainstrom of August 1979 was mainly due to the favourable antecedent basic conditions of moderate to heavy rainfall during the 10 days before the dam failure.

In passing, it may be mentioned that the rainstorm of 25-27 July 1927 referred to by Dhar et al is the same as that discussed under Case No. 3 earlier in our monograph. Figure 18.1 shows the isohyetal pattern of the rainstorm between 10-12 August 1979 over the Machhu basin as delineated

by Dhar et al. The boundary of this basin has been shown by a thick line in the diagram. The position of Machhu-1 and Machhu-2 have also been shown in the diagram. The figure shows that the rainstorm had its heavy rain centre quite close to Rajkot which is only about 20 km to the west of Machhu basin. If this heavy rain centre had been inside the Machhu basin itself, the flood generated would have been greater and the disaster caused by the failure of Machhu-2 would have been even worse.

3. Large-Scale Synoptic Situation and Rainfall Analysis

For convenience of discussion, we are presenting below the large-scale synoptic situation and rainfall analysis in the same section.

During the first week of August, 1979 the synoptic situation was essentially of the type of a mid-tropospheric disturbance, with fluctuations in vertical extent on different days of the week. The upper winds and stream lines at the 700 mb level at 00 GMT on 3 August 1979 may be seen in Figure 18.2

During the second week of August 1979, a monsoonal cyclonic system extending from sea-level upwards caused rainfall over Saurashtra. The text of the synoptic situations published in the I.D.W.R. dated 10 August 1979 reads as follows :

"The deep depression over central parts of Madhya Pradesh weakened into a depression last evening and lies at 0300 GMT of today about 100 km northwest of Bhopal. It is likely to move westwards and gradually weaken." Figure 18.3 shows the circulation at 00 GMT upper winds and stream lines at the 700 mb level at 00 GMT on 10th :

It is important to note that the heavy rainfall occurred :

(a) in association with a weakening of the cyclonic system and which was expected to weaken further and

(b) the centre of the weakening cyclonic system at 0300 GMT was *quite far away* (i. e. 650 km away) to the northeast of Rajkot which reported as much as 354 mm of rainfall at 0830 hrs IST on 11th. The close proximity of Saurashtra (same as Kathiawar) to the North Arabian sea and the cyclonic vorticity, which is created cohen the monsoon dead northerlies come in conflict with strong monsoon westerlies, are extremely important factors responsible for large excess of rainfall over Saurashtra in such situations. The author of this monograph has repeatedly stressed this point in this monograph as well as in his earlier publications. In other words nothing should defer a forcaster from stating in such situations that "exceptionally heavy rainfall would occur".

4. Analysis of Satellite Picture

Plate 18.4 shows the Tiros Satellite picture on 11 August 1979 at 1540 hours IST. The most interesting feature of this picture is the dense mass of convective clouds extending *southwestwards* into the east Arabian sea. This is consistent with the flow-pattern shown in Figure 18.3.

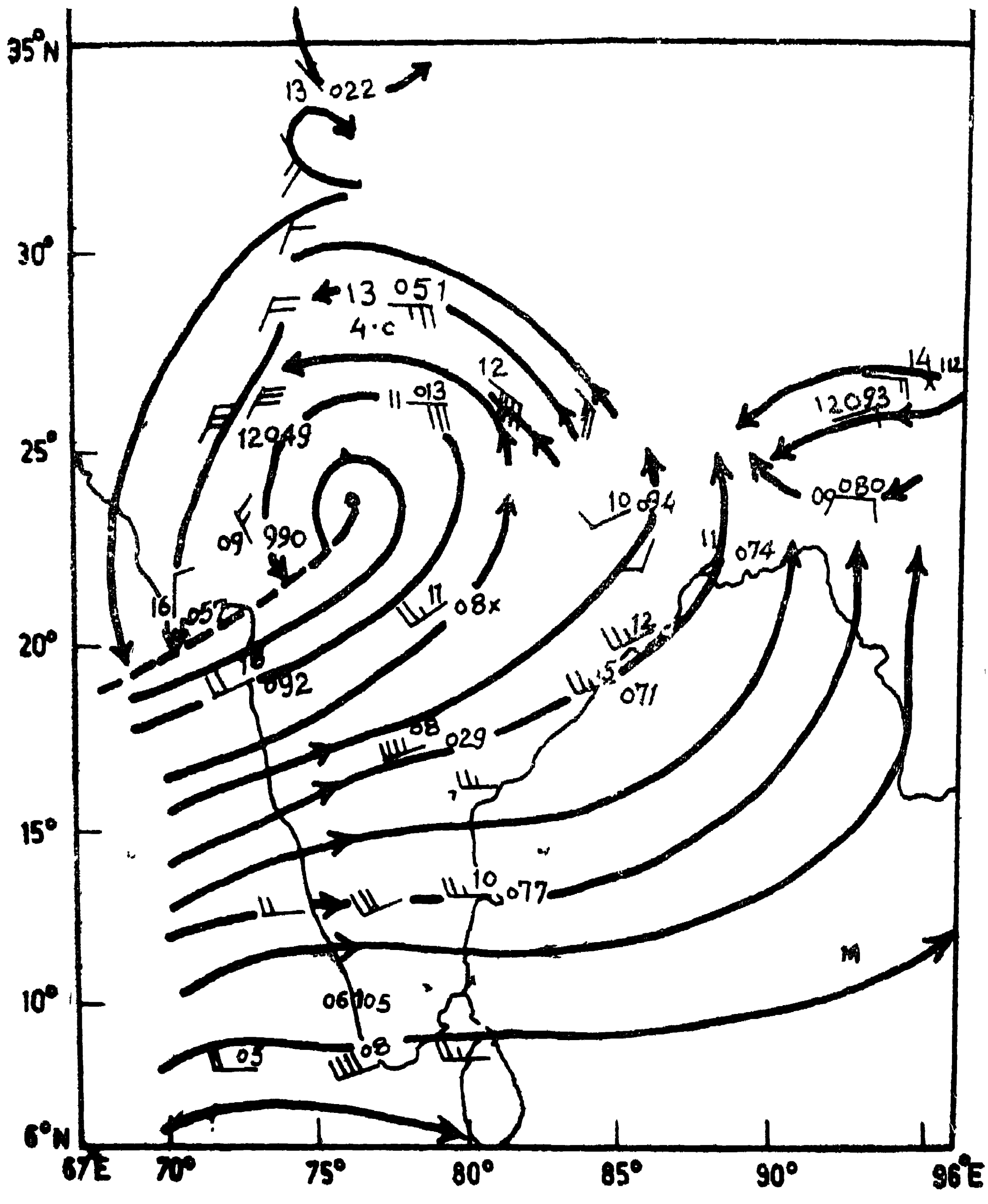


Figure 18.2 Upper Winds and Stream Lines 700 mb 00 GMT 10 Aug 1979

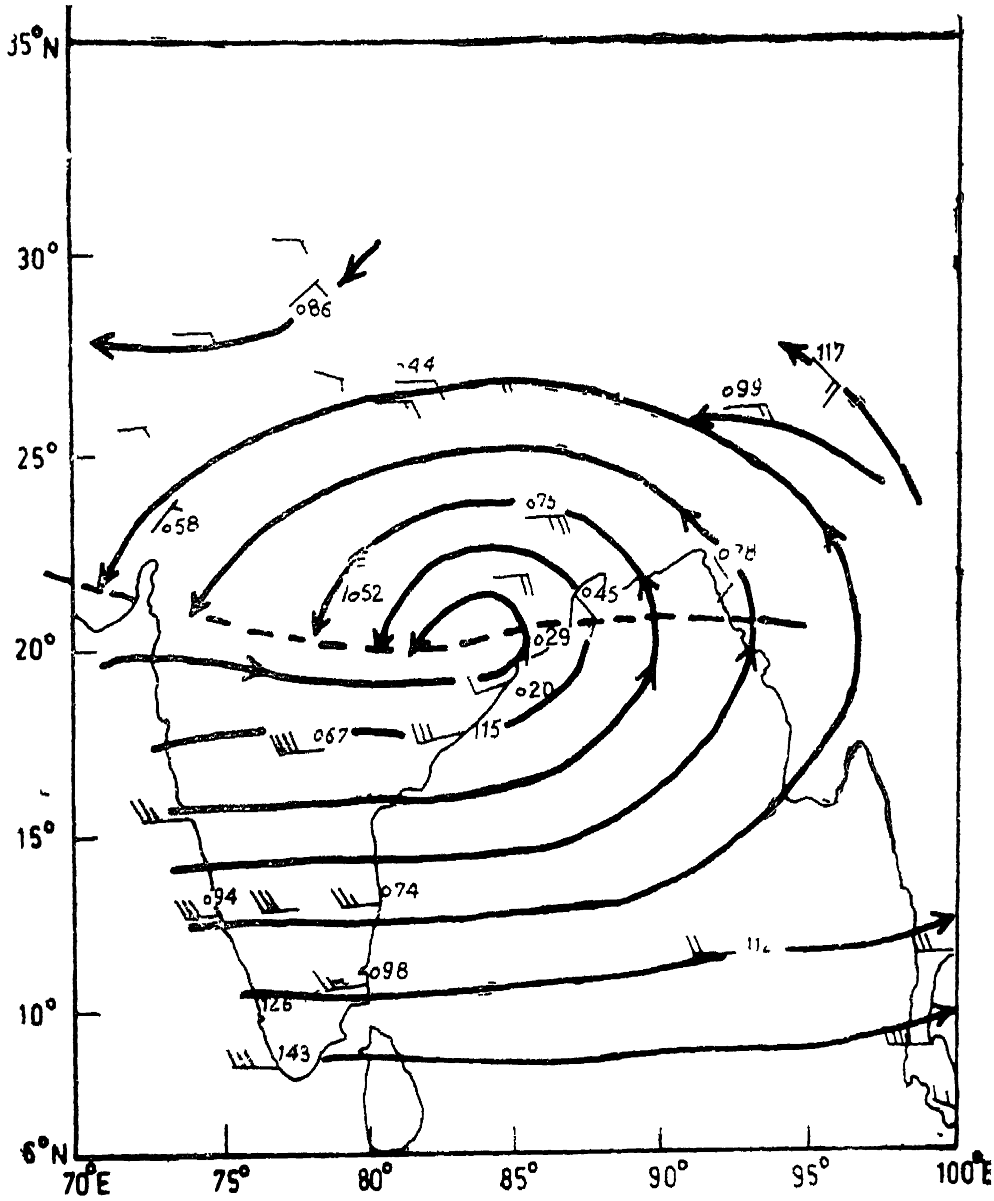


Figure 18 3 Upper Winds and Stream Lines 700mb 00 GMT 3 Aug. 1979

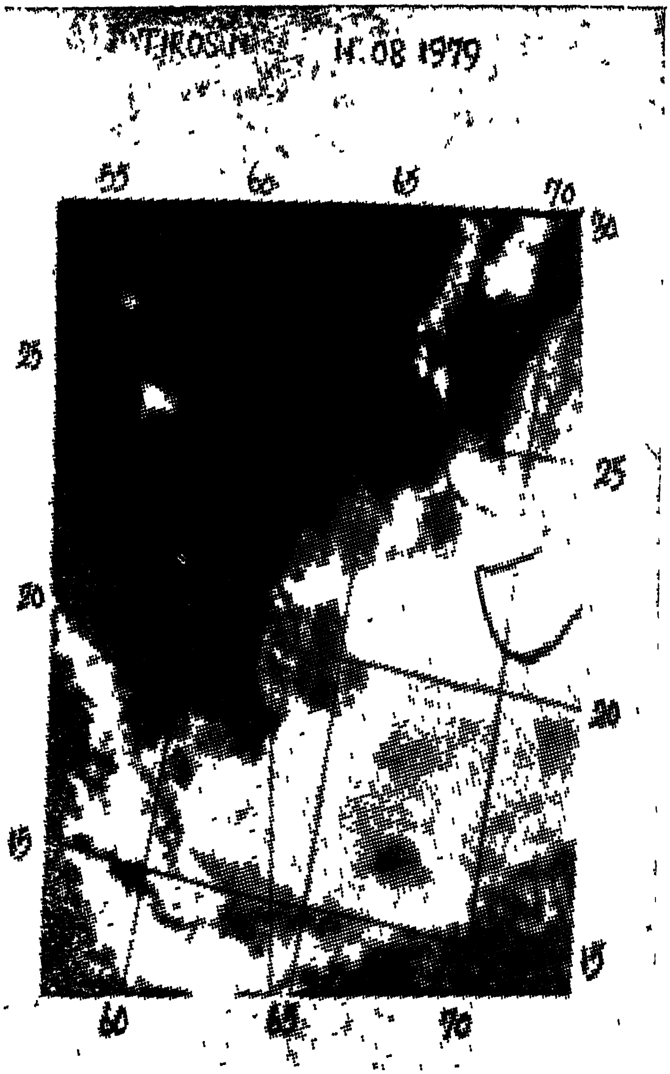


Figure 18 4

5. Flood Damage

We have already described several aspects of the damage caused by these disastrous flash floods. We have therefore nothing specially to add under this section.

CASE No. 19

CATASTROPHIC FLOODS IN UTTAR PRADESH IN JULY, 1980

1. Introduction

These were associated with the northward movement of the monsoon trough at its western end towards the western Himalayas. Embeded lows also moved northwestwards along the monsoon trough towards the hills of west uttar Pradesh. As a result, there was concentrated heavy rainfall in the hills of the west Uttar Pradesh and the adjoining plains.

As a result, there were severe floods in the rivers in west U P. Some of the noteworthy falls of rain (in whole centimeters) there, Rae Barelly 17 cm on 12th, Lodhiana 25, Ferozepur 24 and Patiala 10 cms on 13th and Ambala 16, Patiala 15 on 14th.

2. Flood Damage

The Mebar Power House and two Saw-mills below the Power House in Himachal Pradesh were washed away in flash floods.

The floods in Uttar Pradesh claimed 346 lives and inundated an area of 12 million hectares of cropped land. The floods also caused havoc in 10 districts of Bihar State, erased more than 9000 houses and damaged standing crops in about four lakhs hectares.

CASE No. 20

CATASTROPHIC FLOODS IN ASSAM IN JULY 1981

1. Introduction

These were associated initially with a cyclonic circulation moving eastwards into Assam and later with the shifting of the monsoon trough to the foot of the Himalayas by 26th June and later persisting these by the 4th July. The noteworthy heavy falls (in centimeters) were Pasighat in extreme northwest Assam on 27th June, Agra 26, Kangra (Punjab) 22, New Delhi (SFD) 19, Varanasi City 13 and Hissar 12 on 30th. According to Press Reports the Brahamaputra and its tributaries were in spate and inundated the riverine areas in Dibrugarh district in Assam. About 500,000 people have been affected by floods in Assam.

2. General Conclusions Regarding the Forecasting of Severe and Catastrophic Floods in India

The author submits that his studies of the large number of cases of heavy rainfall and floods, some of which have been discussed in detail here, have provided new insight into the mechanism of these phenamena and that if his suggestions are followed in day-to-day practice, there should be improvement in forecasting these phenomena. In stating this, the author assumes that receipt of high level data from the neighbouring countries will significantly improve in the foreseeable future.

Our general conclusions are summarised below with special reference to the river-systems in our country.

2.1 Indues-system and Upper Ganga Basin

The sevenr and catastrophic floods in these rivers are essentially the result of interaction of middle latitude high-level systems and low latitude low-level monsoonal systems. Recurving monsoon depressions or low pressure areas play a vital role in their interaction. Hence a careful watch has to be kept on monsoon depressions/low pressure areas, recurving to the north towards the Himalayas. Until Numerical Weather Prediction comes into operational use, synoptic meterologists have to issue their forecasts by the usual conventional methods only. They *should not wait* until they actually see, on synoptic charts, the monsoon depressions or low pressure areas recurving to the north. If they wait to see the complete recurvature, the warnings will be sent too late. The forecasters have to take a 'calculated risk' in this respect until adequate upper air data are received from Pakistan, Afghanistan and Iran. It is also important to *bear in mind that very heavy rainfall can occur far ahead of the centre of the monsoon depression.*

2.2 Lower Ganga Basin

2.2.1 : In this region, the synoptician has to keep a careful watch :

On the approach of waves in the westerlies (known in Indian meterological literature as Western *disturbances) above the altitude of the Tibetan Plateau* and the movement of the Monsoon trough associated with the eastward movement of waves in the westerlies. The combined effect of these two weather systems results in a "Break in the Monsoon" and very heavy rainfall occurs along and near the foot of the Nepal Himalayas. (The historical case of the disastrous floods in the Kosi in July and August 1954 (Case No. 6) is a good instance in support of our arguments).

2.2.2 : "Breaks in the Monsoon" and development of depressions in the north Bay of Bengal are mutually exclusive. However, in the absence of a break-condition, when depressions form the Bay of Bengal enter West Bengal or Bangladesh, *they tend to remain quasi-stationary over land especially in August.* Under these conditions, keep a watch on the development of a ridge to the west of the depression and/or of a cyclonic development to the *west*

of the ridge. Very heavy rain may, under such circumstances, occur in the lower Ganga Basin.

2.3. Brahmaputra System

"Break-conditions in the monsoon" and eastward moving Western disturbances (usually a combination of both) play an important part in the development of severe floods especially in June. Monsoon depressions from the north Bay of Bengal, moving northeastwards towards Assam are also well-known factors in causing severe floods. Such northeast moving depressions are relatively small in number. Besides these *three factors, there is an important newly-identified factor* : the lee-vortex or lee-trough which develops to the southeast of the Tiberan Plateau These vortices/troughs at the 500 mb level may lead to severe floods in the upper reaches of the Brahmaputra with repurcussions *downstream over the Brahmaputra basin. Importance of the observations of Pasighat (a plain station) cannot be over-emphasized as they help us* to identify the lee-vortex/lee-trough.

2.4. Central India Basins (including the Mahanadi and Kathiawar and Kutch)

Keep a careful watch on developments in South China sea and the westward movement of low pressure waves from these sea-areas. It is also important that data of sea surface temperatures must be regularly obtained by sophisticated methods and studied to enable us to prognosticate the region of formation of the depressions out in the sea and their movement. Once a depression forms in the north Bay of Bengal, a careful watch must be kept on westward *spreading of deflected monsoon northerlies.* Remember that very heavy rainfall can occur *far ahead of the centre of the monsoon depression* as for instance on 2nd July 1941. The 24 hours largescale sea-level pressure changes can give very useful indications of the direction of movement of monsoon depressions over land. In this respect, tropical depressions differ greatly from middle latitude systems. A change in direction of the movement of the depression from west to southwest or from west to northwest may make all the difference between the development of an ordinary flood and a really severe flood.

2.5. Peninsular Rivers

The number of severe/catastrophic floods in Peninsular India is much less than in the rivers further to the north. The rivers can be grouped as follows :

2.5.1 North Peninsular rivers;

2.5.2 South Peninsular rivers;

2.5.3 West Coast of the Peninsula.

The South Peninsular rivers as far north as Andhra Coast are subject to floods, coastal inundations and *storm snouges* in association with tropical cyclones.

The floods in the Trambaraparani in the Tirunelveli District*, which we have not been discussed here in detail, were probably in the nature of Flash Floods. We do not however claim to have established this fact. The number of occasions of such floods is small.

The North Peninsular rivers some what resemble Central Indian rivers in regard to the flood-problem.

In the West Coast of the Peninsula, the effect of Orography due to the Western Ghats is certainly less than what it was once believed to be. While the waves in the easterlies (especially in the middle troposphere) Considerably influence the phenomenan of floods, the influence of the Tropical Easterly jet and meso-scale off-shore vortices need further investigation.

2.6. Weather Satellite Pictures and their usefulness in forecasting

The total number of satellite pictures available for our study was rather small. They were, however, very useful in forecasting *e.g.* the heavy rainfall in the uppermost reaches in the mighty Indus, in the Teesta in October 1968 (Case No. 12). The weather satellite pictures thus provide an additional tool in identifying synoptic disturbances and forecasting their movement over regions wherefrom high level/conventional data may not be available.

2.7. The Steering Concept

Our study has shown that the steering concept, as clarified by us, is a useful practical tool in forecasting the direction of movement of monsoon depressions, especially over the Central India river basins.

*This district is contiguous to Ramanathapuram district referred to by Abbi (1981),

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